MANUAL
OF
HEATING AND VENTILATION

SCHUMANN.

DATE DUE

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A MANUAL

OF

HEATING AND VENTILATION,

IN THEIR

PRACTICAL APPLICATION,

FOR

THE USE OF ENGINEERS AND ARCHITECTS.

EMBRACING

A SERIES OF TABLES AND FORMULAS FOR DIMENSIONS OF HEATING FLOW AND RETURN PIPES, FOR STEAM AND HOT WATER BOILERS, FLUES, ETC., ETC.

BY

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PREFACE.

In the following pages it is my object to give concisely, the formulæ and data necessary for computing the proper dimensions, etc., of Heating and Ventilating appliances, with a brief statement of the general principles upon which they are based.

It is not intended as a theoretical work, but as a vade-mecum or book of reference for those having the necessary theoretical knowledge, and requiring a convenient and handy book containing the results of theory, relative to the subject, in a form suited for practical application.

The deductions of European authors, made use of, have been modified to suit the conditions of our climate, practice, etc.

CONTENTS.

HEATING AND VENTILATION.

GENERAL PRINCIPLES.

Hot water apparatus, where the temperature in the boiler does not exceed 212°, should be adopted for buildings occupied continuously, and where steam from power boilers is not available, for instance: Schools, Court rooms, Hospitals and Dwellings; steam on the other hand, for Churches, Theatres, Public Halls occupied at intervals, and such other buildings where steam is used as power and the application of the waste for heating purposes is practicable.

The choice of Direct or Indirect radiation, will depend on the construction of the building, and on the purposes for which it is intended. It is sometimes impossible to obtain sufficient space in walls for heating flues; or it may be objectionable to supply the radiators in the cellar or basement with air that might be contaminated by being taken from near the sidewalk or damp and unclean areas, when it would be an easy matter to supply direct radiators through openings in window breasts; on the other hand, direct radiators in a room may interfere with the decorations, or it may be difficult to supply the fresh air. Direct radiation is the most economical, for the reason that radiant heat is utilized, while in indirect radiation it is partially lost.

DIRECT RADIATION.

In direct radiation, the coils or radiators R, are placed in the room (if possible on the coldest side) they are intended to warm; the fresh air being conveyed to them, through flues F, to the lowest part of the coils, the flow of air being regulated by a damper D.

The fresh air is heated by contact with the radiators R, the

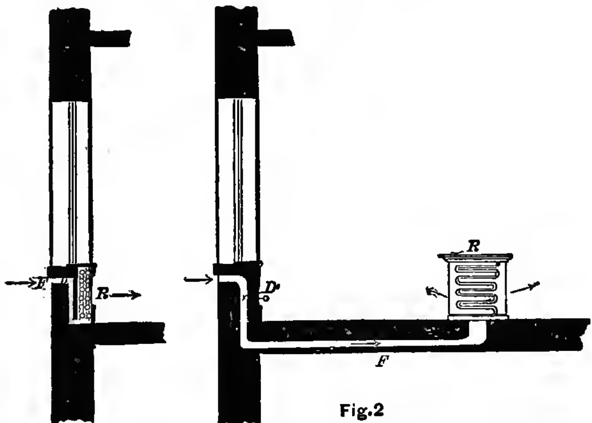


Fig. 1

Fig. 2

Arrows show direction of currents.

surrounding walls and solid objects absorbing a certain amount of radiant heat and again heating the air by contact.

Radiant heat does not heat the air through which it passes, to any appreciable extent.

The intensity of heat emitted by a plane surface, decreases with the sine of the angle formed between the direction of the rays, and the surface at the point of emission; therefore circular surfaces are more effectual than plane ones.

INDIRECT RADIATION.

In indirect radiation, the coils or radiators are placed in other rooms than those they are intended to heat, generally the basement or cellar as at R, the fresh air being conveyed to them through flues or ducts F, and heated by contact, and thence through flues or ducts F_1, into the various rooms; the quantity of cold air being regulated by dampers D. The walls and solid objects in the rooms are heated by contact with the warmed air only.

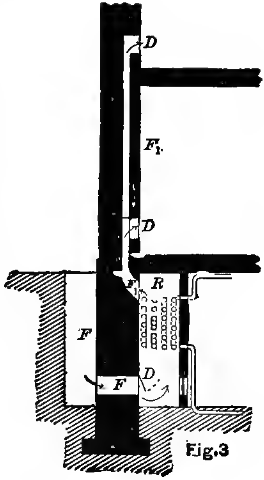


Fig. 3

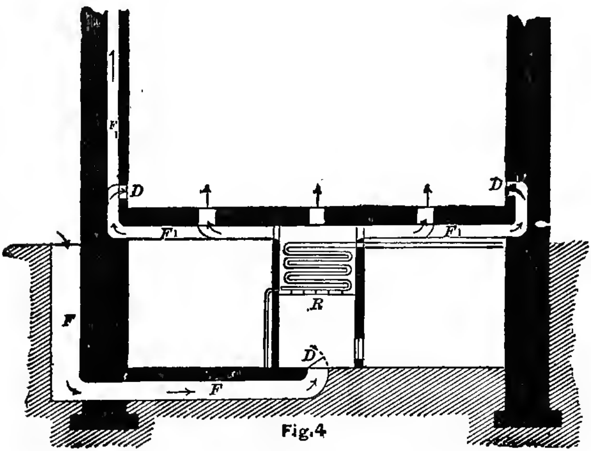


Fig. 4

Arrows show direction of currents.

VENTILATION.

Ventilation is either natural or mechanical or both, the first being by means of openings, such as windows, doors, etc.; the second, by means of fans or chimneys, and the third, both combined, generally for summer ventilation.

MECHANICAL VENTILATION.

Vacuum Movement: Aspirating chimneys exhaust the air from the rooms, thus creating a partial vacuum for the pure air to occupy, coming in through the proper openings. The movement of the air in the chimney is produced by heating and rarefying the air in it; the external air, being heavier, tends to push it up out of the chimney; the fire or heater should be at the lowest point of the chimney. Exhaust fans fulfill the same functions as aspirating chimneys; they may be located under the roof, or in the cellar—the foul air from them being conveyed, through ducts or shafts, away from the building. The vacuum movement requires the doors and windows to be kept closed, during cold weather, so that the fresh air is forced to pass through the heating coils; it has the disadvantage of causing inward draughts through crevices, etc.

Plenum movement: The air is forced in from without by means of fans, the foul air passing off through outlets in walls or ceiling. In rooms so ventilated, there is a slight outward pressure, neutralizing any inward draughts, except through the proper channels.

Mixed movement: Is a combination of the vacuum and plenum, and is applicable when one or the other is not of sufficient power.

CURRENTS.

Currents in ventilated rooms, are either directed upward or downward; in the upward direction, the pure air is admitted at or near the floor, the impure air passing off at or near the

ceiling. In the downward direction, the pure air is admitted at or near the ceiling, or through inlets in the walls near the floor, and the impure air, passing off through the floor, or openings in the walls near the floor. Public places above 15 ft. high, where large crowds assemble, should have the upward direction; smaller rooms, offices, dwellings, etc. may be ventilated downwards.

The pure air inlets should be equally distributed around the room, with the outlets for the impure air, in such position, as to cause the currents to sweep the whole room, being careful for instance, not to place an outlet directly over an inlet.

In the upward movement, the inlets may be in the floor, in risers of platforms, in sides of walls near the floor, in stationary desks, and in the front of stationary benches, etc., etc., etc. The outlets may be in the cornice, or ceiling, or side of walls near the ceiling. This method requires no changes with the seasons—the fresh air, in summer, entering in the same way that it does in winter, when the coils are heated. In the downward movement, on the other hand, the fresh air, in summer, may be admitted at or near the floor, and passed off, at or near the ceiling. Where windows are available, and so placed that currents pass through the room, no provisions need be made in either method for summer ventilation except when there is an object to keep them closed to exclude noise and dirt.

PROPER VELOCITY OF CURRENTS, IN FEET, PER SECOND.

	FEET.
When entering at or near the ceiling and descending,	1.8
When entering at or near the ceiling and horizontal, (when the openings are not less than 12 ft. above the floor.),	4.0
When entering at or near the floor, maximum......	2.0
In ducts, shafts, etc..........................	3 to 10.0

To illustrate the theory of ventilation, let us assume a room to be filled with colored water, to represent vitiated or foul air,

and the room to be completely submerged in clear water, to represent pure or external air. As air and water are subject to the same laws in regard to flow, it follows:

First: If the room be perfectly tight, there will be no exchange or mixture between the colored and clear water, and consequently no ventilation.

Secondly: If openings be provided on sides, top and bottom of the room, the colored and clear water having the *same* temperature, no mixture or ventilation will occur, except through gradual diffusion equally through all openings.

Thirdly: If the clear water be of a *higher* temperature than the colored, the colored water will flow out of the lower openings, it being heavier, and the clear water will enter through the upper openings, filling the room, as the colored water leaves it.

Fourthly: If the clear water be of a *lower* temperature than the colored, it will enter through the lower openings, pushing the colored water, which is lighter, out of the upper openings.

From the above it follows, that: In cold weather, when the temperature of a room is higher than the external air, the air should be admitted at the bottom, and passed off at the top of a room; on the other hand, in warm weather, when the temperature of the room is lower than the external air, the pure air should be admitted at the top, and passed off at the bottom, thus. See Fig. 5.

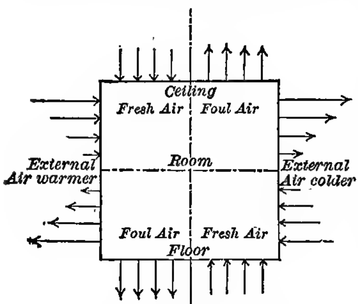


Fig. 5

Arrows show direction of currents.

The movement as explained above, can be reversed by either the vacuum or plenum methods, when desirable, but, if possible, the movements caused by artificial means, should

coincide with and assist those effected by nature (gravity), it being certainly more economical, when perfect ventilation is required.

VACUUM MOVEMENT.

Fig. 6 represents a section through a building showing the application of different kinds of heating and ventilation.

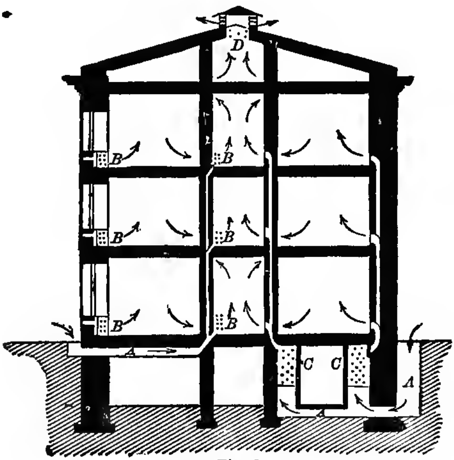


Fig. 6

A section through a building. Arrows show direction of currents.

Direct radiation, currents downward.	Currents upward.	*Indirect radiation,* currents downward.

REFERENCE :—

A, fresh air duct.

B, direct radiators.

C, indirect "

D, coils in ridge for assisting ventilation by rarefying the air at the outlet of ventilating flues.

Fig. 7 is a section through a building having an aspirating and a supply shaft.

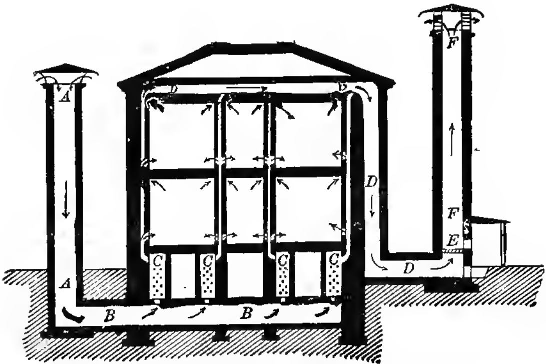


Fig. 7

Arrows show direction of currents.

Ventilation: Vacuum movement; Heating: Indirect radiation; Currents: Upward direction.

REFERENCE:—

A, fresh air supply shaft.
B, duct conveying fresh air to coils.
C, coils.
D, duct conveying foul air to chimney.
E, fire and grate.
F, aspirating chimney.

PLENUM MOVEMENT.

Fig. 8 is a section through a building showing the arrangement of supply shaft, fan, radiator or coil, and ridge ventilation.

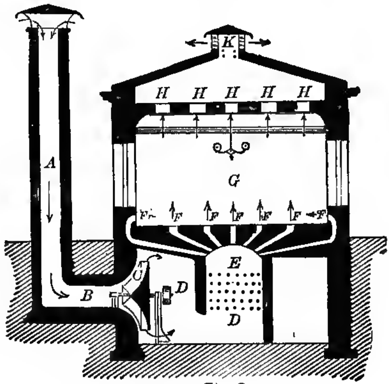


Fig. 8

Arrows show direction of currents.

Ventilation: Plenum movement; Heating: Indirect radiation; Currents: Upward direction.

REFERENCE:—

A, is the fresh air supply shaft.
B, duct leading to fan.
C, the fan.
D, duct leading from fan to coils.
E, heating coils under the room.
F, flues transmitting the heated air to room.
G, room.
H, outlets in ceiling.
K, coils in roof ventilator, to prevent the cold air from coming in.

LOSS OF HEAT in ventilated rooms is caused by:—

1st. Units of heat required to warm the air passing through the room.
2d. Units of heat absorbed by surrounding walls.
3d. Units of heat absorbed by ceiling.
4th. Units of heat absorbed by floor.
5th. Units of heat absorbed by windows.

SOURCES OF HEAT in rooms are:—

1st. Units of heat generated by the occupants.
2d. Units of heat generated by the gas-lights, oil lamps and candles.
3d. Units of heat generated by the heating apparatus.

It has been found by experience, that an adult man requires hourly, for respiration and transpiration, 215 cubic feet of atmospheric air, or $215 \times 0.077 = 16.5$ lbs., and generates about 290 units of heat, of which 99 units are dissipated in the formation of vapor, leaving 191 units to be dissipated by radiation to the surrounding objects, and by contact with colder air.

The quantity of air required, and the heat generated by gas lights, can be estimated with sufficient approximation for practical purposes. The specific gravity of gas, is about ½ that of atmospheric air, or 0.038 lbs. per cubic foot, and requires for complete combustion, $0.038 \times 17 = 0.65$ lbs. of air, or $\frac{0.65}{0.077} = 8.44$ cubic ft. Each cubic foot of gas burned emits about 600 units of heat.

An oil lamp with a moderately good wick, consumes about 154 grains per hour = 35 lamps per pound. Each lb. of oil demands 150 cubic ft. of air for complete combustion and generates about 16,000 units of heat, or 460 per lamp. Candles, 6 to the lb. may be reckoned the same as a lamp consuming oil, each candle burning about 170 grains per hour.

These data tabulated, give in round numbers;

An adult man vitiates per hour................	215	cubic ft.
Every cubic foot of gas burned...............	8.5	" "
Every lb. of oil burned......................	150	" "
Every lb. of candles, 6 to a lb................	160	" "

Units of heat generated by an adult, per hour.........	191.
Units of heat generated by one cubic ft. of gas.........	600.
Units of heat generated by one lb. of oil or candles	15,000 to 18,000.

An average gas burner consumes about 4 feet of gas per hour $= 600 \times 4 = 2,400$ per burner....	2400 units per hour.
Each flame from an oil lamp........430 to 515	" "
Each candle....................454 to 545	" "

VENTILATION.

AIR SUPPLY.

Air vitiated:—The following are some of the vitiating causes:

1st. Respiration and transpiration of human beings.
2d. Respiration and transpiration of animals.
3d. Burning of candles, oil lamps and gas-lights.
4th. Operations generating smoke.
5th. Operations generating dust and its disturbance.
6th. Mechanical and chemical processes generating steam and gases.

An adult man, under ordinary circumstances, requires for respiration and transpiration, 215 cubic ft. per hour, to be multiplied by a factor so that the per cent. of vitiation shall not exceed certain limits.

Every cubic foot of gas consumed, requires for complete combustion, and that the air remains pure, 1,800 cubic ft. per hour.

Every pound of oil or candles consumed, 18,000 cubic ft. of air per hour, or ten times as much as gas.

Air supply:—The following formulæ will demonstrate the necessity of a greater supply of pure air than is vitiated by an adult per hour, so that the percentage of vitiation will not exceed certain limits.

Let V = Volume of fresh air in cubic ft. to be supplied per hour.
v = Volume of air vitiated per hour = 215 cubic ft. per adult.
p = Per cent. of vitiation admissible.
C = Cubic contents of room to be ventilated.
V_1 = Volume of pure air in room after a time, t.
v_1 = Volume of vitiated air in room after a time, t.

After a time, t, V and v, approach certain values, V_2 and v_2, that is: $V_2 = C\frac{V}{V+v}$ and $v_2 = C\frac{v}{V+v}$. Should, for instance, only so much air be supplied as is vitiated, that is, $V = v$, then will $V_2 = \frac{C}{2}$ and $v_2 = \frac{C}{2}$; in words, after a time, t, half of the volume would be pure and half vitiated; this proves that it is not sufficient to supply just so much air as is vitiated, because a room, in a healthful condition, must not contain more than from 5 to 15 per cent. of vitiated air; therefore:

$$p = \frac{V_2}{C} = \frac{v}{V+v};\ V_2 = Cp;\ C = \frac{V_2}{p};\ \text{and}$$

$$\frac{V}{v} = \frac{1-p}{p};\ V = v\frac{1-p}{p};\ v = \frac{V}{\frac{1-p}{p}};\ p = \frac{v}{V+v};\ \text{hence}$$

when p =	0.02	0.03	0.04	0.05	0.06	0.07	0.08
V will be	49	33	24	19	16	13	12
	0.09	0.10	0.11	0.12	0.13	0.14	0.15
	10	9	8	7	6.7	6	5.6

times v respectively; consequently, a room, to contain not more than from 15 to 2 per cent. of vitiated air, must be sup-

plied with from 5.6 to 49 times more fresh air than is vitiated, plus the quantity required for illuminating purposes.

The following are some values for p, when $v = 215$ cubic ft. per hour:

Barracks and Dwellings.	$p = 0.15$ by day; $p = 0.10$ by night.
Workshops...........	$p = 0.10$
Prisons...............	$p = 0.10$
Theatres..............	$p = 0.10$
Schools...............	$p = 0.15$
Hospitals.............	$p = 0.07$ by day and night.
"	$p = 0.05$ during hours of dressing.
"	$p = 0.04$ during epidemics.

EXAMPLE:—A hall, $40 \times 40 \times 20 = 32{,}000$ cubic ft., having 30 occupants, and illuminated by thirty gas lights, each consuming 4 cubic ft. of gas per hour, how much pure air must be supplied per hour so that the limit of vitiation shall not exceed 0.10 per cent.?

$$v = 215 \times 30 = 6450$$

$$V = v\,\frac{1-p}{p} = 6450\,\frac{1-0.10}{0.10} = 6450 \times 9 = 58050 \text{ cubic ft.}$$

for the occupants, and
for illumination per hour $1800 \times 30 \times 4 = 216000$ cubic ft.

Total, per hour........................274050 cubic ft.

The air in the hall changing $\dfrac{274050}{32000} = 8.56$ times per hour, and the inlet areas required, for a velocity of 1.5 ft. per second $= \dfrac{274050}{1.5 \times 60 \times 60} = \dfrac{274050}{5400} = 50.7$ sq. ft.

Carbonic acid :—The per cent. of carbonic acid contained in the air of a room, should be as near to that contained in air of normal condition, viz., 0.04 per cent., as can be practically obtained by means of ventilation; it should not exceed 0.06 per cent., for rooms continually occupied; when it reaches 0.09 per cent., the air becomes disagreeable to the senses.

To compute the per cent. of carbonic acid in the air of a room supplied with fresh air as per foregoing formulas,

Let p_1 = Per cent. of carbonic acid in the room, with continuous ventilation.

p_2 = Per cent. of carbonic acid in normal air = 0.04.

c = Carbonic acid given out by an adult man per hour = 0.6 cubic ft.

q = Volume of air in cubic ft. per man, per hour.

Then will: $q = \frac{c-p_2}{p_1-p_2}\,100$; and $p_1 = \frac{100}{q}(c-p_2)+p_2$.

EXAMPLE :—

$p = 0.10$; $q = 215 \times 9 = 1935$;

$$p_1 = \frac{100}{1935}(0.6-0.04)+0.04 = \frac{100 \times 0.56}{1935}+0.04 = 0.0689,$$ a little more than the standard of 0.06 per cent. To reduce it to 0.06 per cent., q would have to equal $\frac{0.6-0.04}{0.06-0.04}\,100$

$$= \frac{0.56}{0.02}\,100 = 2800$$ cubic ft. per hour, per man.

FLOW OF AIR IN ASPIRATING CHIMNEYS OR VENTILATING SHAFTS.

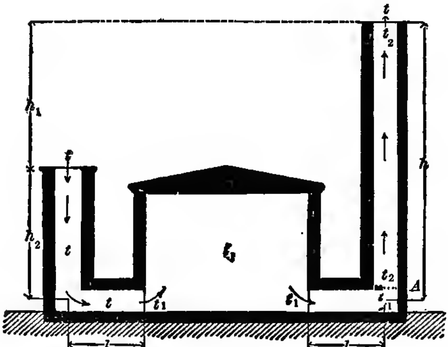


Fig. 9

REFERENCE:—See Fig. 9.

h = Height of chimney $= h_1 + h_2$.
l = Total length of ducts $= h + h_2 + l_1 + l_2$.
f = Coefficient of friction in ducts, etc.
f_1 = " " in elbows, etc.
g = Accelerated gravity = 32.166 ft.
e = Expansion of air per 1° temp. = 0.00208.
A = Sectional area of duct, etc.
p = Periphery of area.
u = Units of heat in 1 lb. of coal on grate A.
% = Per cent. of loss by radiation through walls of chimney.
k = Number of lbs. of coal used per hour.
s = Specific heat of air = 0.238.
U = Units of heat per hour in chimney.
W = Weight of air in lbs. carried off per hour.

V = Volume of air passing through chimney per hour.
w = Weight of a cubic ft. of air of the internal temp., t_1.
v = Velocity of air in ft. per second in ducts.
t = External temperature.
t_1 = Internal temperature in room.
t_2 = " " in chimney.
t_3 = Increase of temperature in chimney, by fire, etc.

$$v = \sqrt{\frac{e\,(t_2 - t)}{1 + et} \cdot \frac{2gh}{1 + f\frac{l}{d} + f_1}}; \quad h = \frac{v^2 (1 + et) \left\{ 1 + f\frac{l}{d} + f_1 \right\}}{2g\,(t_2 - t)\,e}$$

$$U = u\%k; \quad t_3 = \frac{U}{sW}; \quad W = Vw; \quad k = \frac{t_3\,sW}{u\%}; \quad t_2 = t_3 + t_1;$$

$$t_3 = \frac{v^2 (1 + et) \left\{ 1 + f\frac{l}{d} + f_1 \right\}}{2ghe} - (t_1 - t); \quad d = \frac{4A}{p};$$

$$V = 3600Av; \quad A = \frac{V}{3600v}$$

u, generally for coal = 6000.

$\% = 0.90.$

COEFFICIENTS OF FRICTION.

$f = 0.024$; or $\dfrac{0.217}{\sqrt{v}}$; for rough flues $f = 0.05$.

Air passing from a smaller to a larger flue, through an opening in a wall, Fig. 10.

Fig. 10

A, A_1, A_2, = areas of flues, etc.; $a = 0.60$.

$$\text{When } A > A_2,\ f_1 = \left\{ \frac{A}{A_1 a} - 1 \right\}^2;$$

$$\text{when } A_1 = A_2 < A,\ f_1 = \left\{ \frac{A}{A_1} - 1 \right\}^2.$$

Air passing from a larger to a smaller flue, Fig. 11.

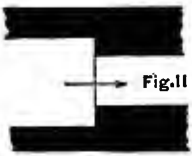


Fig. 11

$$f_1 = \left\{ \frac{1}{a} - 1 \right\} = 0.444;\ \text{say } 0.50.$$

Air passing through a wall or plate, Fig. 12.

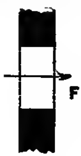


Fig. 12

$$f_1 = 0.50.$$

Square Elbow, Fig. 13. Circular Elbow, Fig. 14.

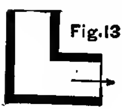


Fig. 13

$$f_1 = 1.50.$$

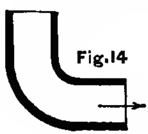


Fig. 14

$$f_1 = 0.50.$$

FLOW OF AIR IN ASPIRATING CHIMNEYS OR VENTILATING SHAFTS.

EXAMPLE:—See Fig. 9. Shaft and ducts square.

Let $u = 6000 \times 0.90 = 5400.$

$s = 0.238.$

$h = 150$ ft.

$h_2 = 100$ ft.

$A = 5 \times 5 = 25$ sq. ft.

$l = h + h_2 + l_1 + l_2 = 150 + 100 + 10 + 10 = 270$ ft.

$t = 50°.$

$t_1 = 70°.$

$t_2 = 90° = t_3 + t_1 = 20° + 70°.$

$f = 0.05$ for brick flues.

f_1 for two square elbows $= 1.5 \times 2 = 3.0.$

$$d = \frac{4 \times 25}{5 \times 4} = 5;$$

$$v = \sqrt{\frac{e(t_2 - t)}{1 + et} \cdot \frac{2gh}{1 + f\frac{l}{d} + f_1}}$$

$$= \sqrt{\frac{0.00208(90 - 50)}{1 + 0.00208 \times 50} \cdot \frac{2 \times 32.166 \times 150}{1 + 0.05\frac{270}{5} + 3}}$$

$$= \sqrt{\frac{0.08320 \times 9650}{1.104 \times 6.7}} = \sqrt{\frac{802.88}{7.4}} = \sqrt{108.5}$$

$= 10.4$ ft. per second.

$V = Av\,3600 = 25 \times 10.4 \times 3600 = 936000$ cubic ft. per hour.

$W = Vw = 936000 \times 0.075 = 70200$ lbs.

$$k = \frac{20 \times 0.238 \times 70200}{5400} = 62 \text{ lbs. of coal per hour.}$$

FANS.

FOR VACUUM OR PLENUM MOVEMENT, ACCORDING TO RITTINGER.

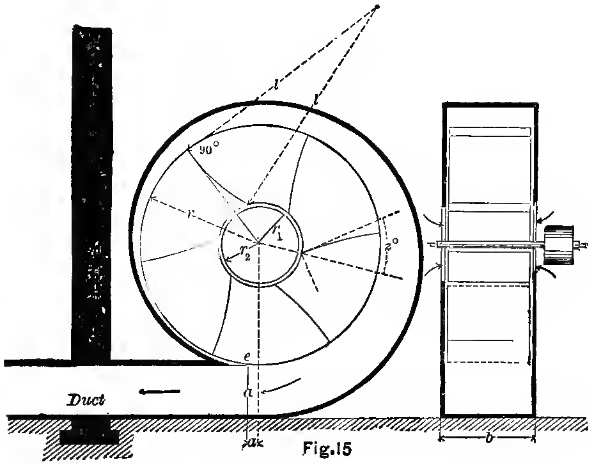


Fig. 15

REFERENCE:—See Fig. 15.

V = Volume of air delivered in cubic ft. per second.
h = Height manometer, in duct, in feet; generally 0.05 to 0.6 feet.
c = Velocity of the air entering the fan.
c_1 = Velocity of the air leaving the fan.
r = Outer radius of vanes.
r_1 = Inner radius of vanes.
r_2 = Radius of inlet.
l = Radius for the curve of vanes.
b = Width of vanes.
a = Height of outlet.
a_1 = Distance from vertical radius to point e_1.

n = Number of revolutions per *minute.*
z° = Angle between radius and initial line of vane.
Hp = Horse power required.

When there is only one inlet,

$$r_2 = \sqrt{\frac{V}{c\pi}};$$

$$b = \frac{r_2^2}{2\,r_1};$$

When there are two inlets,

$$r_2 = \sqrt{\frac{V}{2c\pi}};$$

$$b = \frac{r_2^2}{r_1};$$

$$b = \frac{V}{2\pi r_1 c};$$

$$r_1 = r_2 \text{ to } 2\,r_2;$$

$$n = \frac{2636}{r}\sqrt{h};$$

$l = \dfrac{r^2 - r_1^2}{2r_1\,sin.\,z^\circ}$, in which the tangent $z^\circ = 0.1047\,\dfrac{n\,r_1}{c}$ describes a curve from the point e, to the inner periphery of vanes.

$a = \dfrac{V}{bc_1}$, in which $c_1 = \sqrt{\left\{\frac{r_1}{r}c\right\}^2 + 0.011\,n^2 r^2}$;

$a_1 = 0.159\,a$;

The % of effect is generally 60, therefore

$$Hp = \frac{62.5}{550}\,\frac{100}{40}\,Vh = 0.28Vh.$$

The shell of this fan has the form of an archimedean spiral, beginning at point e.

The number of vanes $= 10\,r_1$, generally 4 to 6.

c = 10 to 40 ft. per second.

EXAMPLE:—How many horse power are required to deliver 260 cubic ft. of air per ~~minute~~ sec, when $h = 0.1$?

$Hp = 0.28Vh = 0.28 \times 260 \times 0.1 = 7.28$, requiring about $7.28 \times 8 = 58.24$ lbs. of coal per hour.

FANS.

FOR VACUUM OR PLENUM MOVEMENT, ACCORDING TO COMBES.

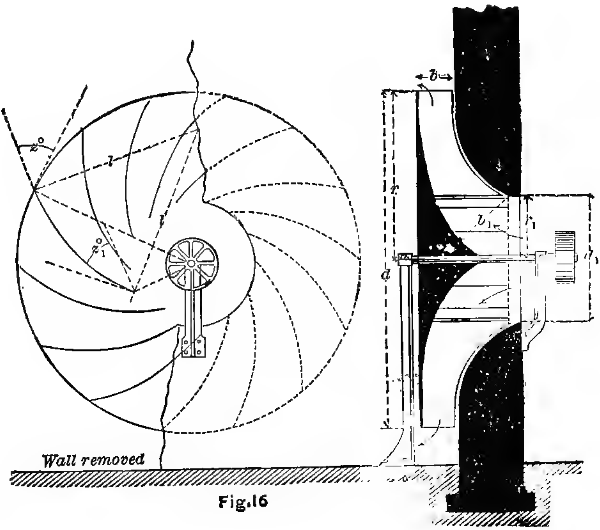


Fig. 16

REFERENCE:—See Fig. 16.

A = Sectional area of air current, as it leaves the fan.

A_1 = Sectional area of air current, as it enters the fan.

V = Volume of air delivered in cubit ft. per second, theoretical quantity.

V_1 = Volume of air delivered in cubic ft. per second, actual quantity passing through the duct.

b = Width of fan, outside.

b_1 = Width of fan, inside.

c = Velocity of air entering the fan, theoretical.

c_1 = Velocity of air leaving the fan, theoretical.

c_2 = Velocity of air leaving the fan, actual.
d = Outer diameter of fan.
d_1 = Inner diameter of fan.

$$e = \frac{\text{Column of air}}{\text{Column of water}} = \frac{28133}{33.95} = 829.$$

g = Force of gravity = 32.166 ft.
h = Height of manometer, from 0.025 to 0.2 ft.
k = Per cent of effect, from 20 to 30.
l = Radius for vanes = $\frac{1}{2}$d to $\frac{2}{3}$d.
n = Number of revolutions per second, from 1 to 2.
r = Outer radius of vanes.
r_1 = Inner radius of vanes.
v = Velocity of periphery of vanes.
z° and z_1° = Angles between tangents and initial line of vanes.
Hp = Horse power required.

$$c = \sqrt{2ghe} \text{ approx.} = \frac{V_1}{A_1} = v\text{, generally from 6 to 30 ft.}$$

$$h = \frac{c^2}{2ge}; \quad v = dn\pi; \quad A = db\pi \, sin \, z^\circ;$$

$$A_1 = d_1 b_1 \pi \, sin. \, z_1^\circ;$$

$$c_1 = \frac{r_1}{r} \frac{b_1}{b} \frac{c}{sin. \, z^\circ}; \quad n = \frac{V_1}{Ac_1} \frac{100}{k};$$

$$V_1 = V \frac{k}{100} = nAc_1 \frac{k}{100}; \quad V = nAc_1 = V_1 \frac{100}{k};$$

$$Hp = \frac{62.5Vh}{550} = \frac{62.5V_1h}{550} \times \frac{100}{k} = 0.113Vh$$

$$= 0.113V_1h \frac{100}{k};$$

$$b_1 d_1 \pi = bd\pi; \quad b = b_1 \frac{d_1}{d}; \quad b_1 = b \frac{d}{d_1}; \quad d = d_1 \frac{b_1}{b}; \quad d_1 = d \frac{b}{b_1};$$

z° = Generally from 40° to 60.°

Number of vanes, $1.5r_1$, generally from 6 to 16.

EXAMPLE :—See Fig. 16.

Required the volume of air delivered by a fan of the following dimensions :—Per cent. of effect, $k = 25$.

$d = 16$ ft.; $r = 8$ ft.; $r_1 = 5$ ft.; $b = 1.25$ ft.; $b_1 = 2.25$ ft.
$z^\circ = \sin. 47^\circ = 0.73$.
$h = 0.025$ ft; $l = 10$ ft.; number of vanes 16; and $n = 2$
$= 120$ per minute.

$$c = \sqrt{2 \times 32.166 \times 0.025 \times 829} = 36.6.$$

$$c_1 = \frac{5}{8} \times \frac{2.25}{1.25} \times \frac{36.6}{0.73} = 56.4.$$

$$A = 16 \times 1.25 \times 3.1416 \times 0.73 = 45.86.$$

$$V = 2 \times 45.86 \times 56.4 = 5175. \quad V_1 = 5175 \frac{25}{100} = 1293.75.$$

$$Hp = \frac{5175 \times 0.025 \times 62.5}{550} = 14.7,$$ allowing 8 lbs. of coal per horse power $= 14.7 \times 8 = 117.6$ pounds per hour.

NOTE: The sectional area of duct leading from the fan, should not be less than A.

HEATING.

GENERAL PRINCIPLES.

Unit of heat:—Is a standard term for measuring the amount of heat absorbed or emitted during any operation; in the United States and Great Britain, it is the amount of heat necessary to raise the temperature of 1 lb. of water 1° Fahrenheit. Thus, to heat 50 lbs. of water 1° would require $= 50 \times 1 = 50$ units, or if it were required to heat 50 lbs. 20° it would be $50 \times 20 \times 1 = 1{,}000$ units.

Specific heat:—Is the capacity of a body for heat; it is the number of units of heat necessary to raise the temperature of the body, 1° Fahrenheit. See table.

Transmission of heat:—

1st. By radiation; that is, the heated body giving out its heat in rays.

2d. By convection, the heat being conveyed from the heated body through flues.

3d. By conduction, the heat passing from a heated body to a colder one, when in contact.

Loss of heat, or cooling of bodies.—Bodies are cooled;

1st. By radiation.

2d. By contact, (with cold air, or a colder body).

3d. By conduction.

Let T and T_1 = Temp. of air in room, see Fig. 17.
t, t_1, t_2 and t_3 = Temp. of surfaces of walls.
H, be the heated body.
L_1 = Loss of heat by radiation.
L_2 = Loss of heat by contact.
L_3 = Loss of heat by conduction.

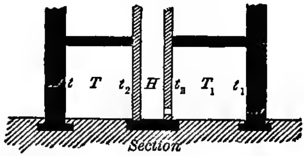


Fig. 17

H will lose:

1st. *By radiation* (L_1), when $T = T_1 = t_2 = t_3 > t = t_1$;
2d. *By contact* (L_2), when $t = t_1 = t_2 = t_3 > T = T_1$;
3d. *By conduction* (L_3), when $T_1 = t_1 = t_3 > T = t = t_2$;
4th. *By radiation, contact and conduction* ($L_1 + L_2 + L_3$), when $t_3 > T = T_1 = t_1 = t = t_2$.

Loss of heat by radiation:—Radiation is not affected by the form of the body, nor by the distance of the absorbing body; it possesses the property of passing through moderate thickness of air or gases without heating them or losing any of its heat, to any appreciable extent. Air and gases can, under ordinary circumstances, be heated by contact only.

Reference:—

L_1 = Units of heat absorbed or emitted per square ft. per hour, by radiation.
r = Factor for loss of heat by radiation, from experiments of Péclet. See table.

t = Temp. in Fahr. of the radiating body.
t_1 = Temp. in Fahr. of the absorbing body.

$$L_1 = 225\,r\left(1.0043^{t-32} - 1.0043^{t_1-32}\right).$$

For small differences between t and t_1 say 30°, when $t_1 = 60°$ to 70°.

$L_1 = r\,(t - t_1)$, will be sufficiently accurate for all practical purposes.

VALUES OF r;

Being the radiating and absorbing power of bodies, in units of heat per square ft., for a difference of 1° Fahrenheit, from the experiments of Péclet:

	r =
Silver, silvered Copper	0.02657
Copper	0.03270
Tin	0.04395
Zinc and Brass, polished	0.04906
Iron, tinned	0.08585
" sheet	0.09200
" ordinary	0.56620
" cast, new	0.64800
" sheet and cast, rusted	0.68680
Lead, sheet	0.13286
Glass	0.59480
Chalk	0.67860
Wood sawdust, fine	0.72150
Building stones, Plaster, Wood, Brick	0.73580
Sand, fine	0.74000
Calico	0.74610
Woolen stuffs	0.75220
Silk stuffs, Oil paint	0.75830
Paper	0.77060
Lampblack	0.81960
Water	1.08530
Oil	1.48000

Loss of heat by contact with air:—The heat absorbed from a body by contact with cold air, is not influenced by the nature of the surface, all materials losing the same amount, under similar conditions of temperature; nor does the form of the body affect the result materially, as was formerly supposed (see Grashof, "Theoretische Maschinenlehre," 1875); the loss varies only with the more or less disturbed condition of the air in contact, which is expressed by the factor $y = 4$, for quiet air, and for more rapidly moving air, as continually renewed air in room, $y = 5$.

REFERENCE:—

L_2 = Loss of heat by contact, per sq. ft. per hour.
t = Temperature of the heated body.
T = Temperature of the air in contact (average).
y = Factor = 4, for quiet air; = 5, for moving air.

$$L_2 = 0.09824y(t - T)^{1.233.}$$

For small differences between t, and T, say 30°, when $T = 60°$ to 70°, $L_2 = 0.09824s(t - T)$ will be sufficiently accurate for all practical purposes.

Loss of heat by conduction:—A wall separates two rooms, A and B; A, having a temperature of 70°, and B, 40°, there will then be a certain amount of heat transmitted through the wall, from A to B; the amount transmitted varying with the material of which the wall is built, and its thickness, for similar conditions of temperature of the surfaces.

REFERENCE:—

Let L_3 = Loss of heat by conduction per sq. ft. per hour.
t = Temperature of heated surface.
t_1 = Temperature of cold surface.
e = Thickness of body between t and t_1.
c = Conducting power of the material, being the quantity of heat transmitted, by a plate, 1 inch thick, the

difference of temperature between the two surfaces, $t - t_1 = 1°$ Fahrenheit, in units of heat, per square foot per hour. See table, page 37.

$$L_3 = \frac{c}{e}(t - t_1).$$

Loss of heat through walls and windows, per square foot per hour.

REFERENCE :—

c = Conducting power of material, as per table, page 37.
e = Thickness of wall or plate, in inches.
r = Radiating power of the material, see table, page 33.
l_2 = Loss by contact of air, for a difference of 1°, see L_2, page 34.
$q = r + l_2$.
T = Temperature of internal air (in room).
T_1 = Temperature of external air.
T_2 = Temperature of internal air in adjoining room.
t = Temperature of internal surface of wall.
t_1 = Temperature of external surface of wall.
t_2 and t_3 = Temperature of surfaces of wall, next to adjoining room.
t_4 = Temperature of glass in windows, etc.
U = Total units of heat lost per hour, per sq. ft.
W = Walls or windows.

Loss of heat through floors :—When the floor is exposed to the external air, the loss of heat will be by conduction only, and the formulas for loss of heat through walls will apply, but when not so exposed this loss will be null.

Loss of heat through ceilings :—When the ceiling is composed of brick arches, concrete, or joists lathed and plastered, and covered by a roof, the loss will be null; but when the roof forms the ceiling, and is either of brick, concrete, slate, tin, glass, etc.,

the loss will be considerable by conduction, the same formulas applying as for walls, etc.

Loss of heat through walls and windows:—When all sides of the building are exposed, Fig. 18.

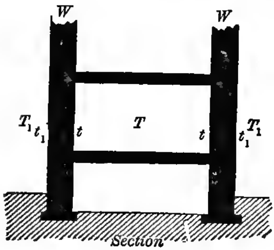


Fig. 18

$$t = \frac{q(el_2T + cT_1) + l_2cT}{c(2l_2+r)+el_2q};$$

$$t_1 = \frac{ct+qeT_1}{c+qe};$$

$$U = l_2(T-t) = \frac{c(t-t_1)}{e} = q(t_1-T_1)$$

$$= \frac{q(t-T_1)}{1+q\frac{e}{c}} = \frac{l_2cq(T-T_1)}{c(2l_2+r)+el_2q}.$$

When one side only of the building is exposed, Fig. 19.

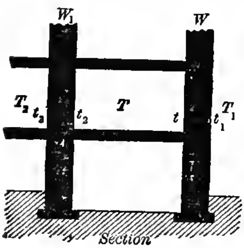


Fig. 19

When $t_2 = T$,

$$t = t_2 - \frac{U}{q}; \quad t_1 = T_1 + \frac{U}{q};$$

$$U = \frac{q\left(\frac{T-T_1}{2} - T_1\right)}{1+q\frac{\frac{e}{2}}{c}} = \frac{c(t-t_1)}{e}.$$

For wall W_1, $t_3 = \frac{r(t_2-t)e}{c} + t_2$; $T_2 = \frac{r(t_2-t)}{l_2} + t_3$.

Loss of heat through glass (windows, etc.):—Windows, etc., of thin glass, not more than ¼ inch thick.

When $T = t = t_2$,

$$t_4 = \frac{T+T_1}{2};$$

$$U = q\,(T-t_4).$$

When $T > t_2$,

$$t_4 = \frac{\frac{(T-t)l_2}{q} + t + T_1}{2};$$

$$U = l_2(T-t_4) + r(t-t_4).$$

When all sides are glass (conservatories).

When $T > t$,

$$t_4 = \frac{(l_2 T) + (l_2 + r)T_1}{2l_2 + r}; \quad U = l_2(T - t_4).$$

CONDUCTING POWER OF MATERIALS.

Value c, being the units of heat transmitted per hour per square foot of a plate 1 inch thick, the two surfaces differing in temp. 1°.

	c =		c =
Copper	515	Pine, parallel to fibres	1.370
Iron	233	Walnut, parallel to fibres	1.400
Zinc	225	Gutta percha	1.380
Lead	113	India rubber	1.370
Marble, gray, fine grained	28	Brick dust, sifted	1.330
Marble, white, coarse grained	22.400	Coke, pulverized	1.290
Stone, calcareous, fine,	16.700	Cork	1.150
" " ordinary	13.680	Chalk, in powder	0.869
Glass	6.600	Charcoal of wood, powdered	0.636
Brick-work, baked clay	4.830	Straw, chopped	0.563
Plaster, ordinary	3.860	Coal, small sifted	0.547
Oak, perpendicular to fibres	1.700	Wood ashes	0.531
Walnut, perpendicular to fibres	0.830	Mahogany dust	0.523
Pine, perpendicular to fibres	0.748	Canvas of hemp, new	0.418
		Calico, new	0.402
		Writing paper, white	0.346
		Cotton, or sheep's wool	0.323
		Eiderdown	0.314
		Blotting paper, gray	0.274

For double windows, when the glass is not less than 2 inches apart, $c = 3.6$.

Stagnant air, $c = 0.3$.

UNITS OF HEAT EMITTED OR ABSORBED PER SQUARE FOOT PER HOUR.

VALUES OF $(t - T)^{1.233} =$		VALUES OF 1.0043^{t-32}.	
When $t - T =$	$(t - T)^{1.233} =$	When t or $t_1 =$	$1.0043^{t-32} =$
10°	17.10	40°	1.034
20	40.19	50	1.079
30	66.20	60	1.126
40	94.52	70	1.175
50	124.40	80	1.226
60	155.76	90	1.280
70	188.36	100	1.336
80	222.08	110	1.394
90	256.79	120	1.455
100	292.42	130	1.518
110	328.88	140	1.584
120	366.13	150	1.653
130	404.21	160	1.725
140	442.77	170	1.800
150	482.08	180	1.878
160	522.01	190	1.960
170	562.53	200	2.046
180	603.61	210	2.135
190	645.21	220	2.240
200	687.34	230	2.338
210	729.95	240	2.441
220	774.83	250	2.548
230	816.61	260	2.659
...	.....	270	2.776
...	.....	280	2.898
...	.....	290	3.025
...	.....	300	3.158

See L_1 and L_2, pages 33 and 34.

Loss of heat by the incoming fresh air:—In ventilated rooms, where a certain amount of fresh air is supplied, and impure air displaced, the heat necessary to raise the fresh air to a given temperature in the room, equals a certain loss per hour.

REFERENCE:—

Let U = Units of heat necessary to warm the fresh air.

T = Temperature of the internal air, generally 70°.

T_1 = Temperature of the external air, see table.

Q = Cubic contents of room, in feet.

n = Number of times that Q is to be renewed per hour.

w = Weight of a cubic foot of air, at the temp. of T_1. p. 44

s = Specific heat of air, see table, page 42.

$$U = Qnws\,(T - T_1).$$

HOT WATER PIPES.

Heated body of cast iron, r = 0.648.

UNITS OF HEAT, u, EMITTED OR ABSORBED, PER SQUARE FOOT PER HOUR.

Mean temp. t, of heated body, pipe, etc.	Temp. T, or t_1, of air and walls.	UNITS OF HEAT PER SQUARE FOOT PER HOUR.				
		By contact, L_2 =		By radiation, L_1 =	By radiation and contact combined, $L_1 + L_2$.	
		y = 3, air quiet.	y = 5, air moving.		y = 3, air quiet.	y = 5, air moving.
70	70	0	0	0	0	0
80	"	5.04	8.40	7.43	12.47	15.83
90	"	11.84	19.73	15.31	27.15	35.04
100	"	19.53	32.55	23.47	43.00	56.02
110	"	27.86	46.43	31.93	59.79	78.36
120	"	36.66	61.10	40.82	77.48	101.92
130	"	45.90	76.50	50.00	95.90	126.50
140	"	55.51	92.52	59.63	115.14	152.15
150	"	65.45	109.18	69.69	135.14	178.87
160	"	75.68	126.13	80.19	155.87	206.32
170	"	86.18	143.30	91.12	177.30	234.42
180	"	96.93	161.55	102.50	199.43	264.05
190	"	107.90	179.83	114.45	222.35	294.28
200	"	119.13	198.55	127.00	246.13	325.55
210	"	130.49	217.48	139.96	270.49	357.48

$$L_1 = 225\,r\left(1.0043^{t-32} - 1.0043^{t_1-32.}\right)$$

$$L_2 = 0.09824y(t-T)^{1.233.}$$

Units of heat u_1, emitted per lineal foot of pipe per hour.

Let d = Diameter of pipe in ft.

$$u_1 = u\,d\,3.1416.$$

STEAM PIPES.

Heated body of cast iron, $r = 0.648$.

UNITS OF HEAT, u, EMITTED OR ABSORBED, PER SQUARE FOOT PER HOUR.

Mean temp. t, of heated body, pipe, etc.	Tempt. T, or t_1, of air and walls.	UNITS OF HEAT PER SQUARE FOOT PER HOUR.				
		By contact, L_2 =		By radiation,	By radiation and contact combined, $L_1 + L_2$ =	
		y=3, air quiet.	y=5, air moving.	L_1 =	y=3, air quiet.	y=5, air moving.
210	70	130.49	217.48	139.96	270.49	357.48
220	"	142.20	237.00	155.27	297.47	392.27
230	"	153.95	256.58	169.56	323.51	426.14
240	"	165.90	279.83	184.58	350.48	464.41
250	"	178.00	296.66	200.18	378.18	496.84
260	"	189.90	316.50	214.36	404.26	530.86
270	"	202.70	337.83	233.42	436.12	571.25
280	"	215.30	358.85	251.21	466.51	610.06
290	"	228.55	380.91	267.73	496.28	648.64
300	"	240.85	401.41	279.12	519.97	680.53

EXAMPLES:—See table, page 38.

Let $t = 210°$; $t_1 = T = 70°$; $r = 0.648$, and $y = 3$.

$$L_1 = 225 \times 0.648(2.135 - 1.175) = 139.96.$$

$$L_2 = 0.09824 \times 3 \times 442.77 = 130.49.$$

Units of heat required, per sq. ft. per hour, of heating surface, to heat 1 cubic foot of air, at different temperatures.

REFERENCE :—

T = Temperature of air in room.
T_1 = Temperature of external air.
s = Specific heat of air = 0.238.
w = Weight of a cubic ft. of air at T_1.
u_2 = Units of heat required, per sq. ft. of heating surface per hour.
u = Units of heat per sq. ft. of surface, per table, p. 39 40.

$$u_2 = ws(T - T_1); \qquad q = \frac{u}{u_2}.$$

q = Cubic ft. of air heated from T_1 to T, per sq. ft. of heating surface.

External temp. T_1=	Temperature of air in room, T=									
	40°	50°	60°	70°	80°	90°	100°	110°	120°	130°
	u_2 =	u_2 =	u_2 =	u_2 =	u_2 =	u_2 =	u_2 =	u_2 =	u_2 =	u_2 =
0°	0.822	1.028	1.234	1.439	1.645	1.851	2.056	2.262	2.467	2.673
10°	0.604	0.805	1.007	1.208	1.409	1.611	1.812	2.013	2.215	2.416
20°	0.393	0.590	0.787	0.984	1.181	1.378	1.575	1.771	1.968	2.165
30°	0.192	0.385	0.578	0.770	0.963	1.155	1.345	1.540	1.733	1.925
40°	0.000	0.188	0.376	0.564	0.752	0.940	1.128	1.316	1.504	1.692
50°	0.000	0.000	0.184	0.367	0.551	0.735	0.918	1.102	1.286	1.470
60°	0.000	0.000	0.000	0.179	0.359	0.538	0.718	0.897	1.077	1.256
70°	0.000	0.000	0.000	0.000	0.175	0.350	0.525	0.700	0.875	1.049

EXAMPLE :—

How many cubic feet of air, moving, will a square foot of cast iron pipe heat, by contact alone, the temperature of pipe being 160°, the external air 40°, and required temperature of room 70°?

By table, $u = 126.13$, and $u_2 = 0.564$;

hence, $q = \frac{u}{u_2} = \frac{126.13}{0.564} = 223.6$ cubic ft. (the answer).

SPECIFIC HEAT OF SOLID, LIQUID, AND GASEOUS BODIES.

Number of units of heat necessary to heat one pound of the body 1° Fahr.	
Iron, wrought	0.1138
" cast	0.1298
Copper	0.0951
Tin	0.0569
Zinc	0.0955
Brass	0.0939
Lead	0.0314
Mercury	0.0333
Gold	0.0324
Silver	0.0570
Platina	0.0324
Bismuth	0.0308
Glass	0.1977
Marble, white	0.2158
Chalk, white	0.2148
Burnt Clay, white	0.1850
Coal	0.2777
Sulphur	0.2026
Spermaceti	0.3200
Wood, pine	0.6500
Wood, birch	0.4800
Beeswax	0.4500
Ice	0.5040
Water	1.0000
Olive oil	0.3096
Alcohol	0.6220
Oil of Temperature	0.4720
Gases under a constant pressure of 30 inches mercury.	
Oxygen	0.2182
Hydrogen	3.4046
Nitrogen	0.2440
Carbonic Acid	0.2164
Sulphuretted Hydrogen	0.2423
Vapor of water	0.4750
Air	0.2380

WEIGHT AND VOLUME OF WATER OF DIFFERENT TEMPERATURES.

REFERENCE :—

V = Volume of water of temp. T, that at 39° being unit.
T = Temperature of water.
w = Weight of a cubic ft. of temp. T.
W = Weight of a cubic ft. at 39°

$$V = 1 + \frac{(T-39)^2}{2000000[0.23+0.0007(T-39)]}; \quad w = \frac{W}{V};$$

WEIGHT AND VOLUME OF WATER OF DIFFERENT TEMPERATURES.

T°	V	w	T°	V	w
32	1.000109	62.387	125	1.012743	61.603
35	1.000035	62.386	130	1.014098	61.521
39	1.000000	62.388055	135	1.015505	61.435
40	1.000002	62.388	140	1.016962	61.347
45	1.000077	62.383	145	1.018468	61.257
50	1.000254	62.372	150	1.020021	61.163
55	1.000531	62.355	155	1.021619	61.068
60	1.000901	62.332	160	1.023262	60.970
65	1.001362	62.303	165	1.024947	60.869
70	1.001909	62.269	170	1.026672	60.767
75	1.002539	62.230	175	1.028438	60.662
80	1.003249	62.186	180	1.030242	60.556
85	1.004035	62.137	185	1.032083	60.449
90	1.004894	62.084	190	1.033960	60.339
95	1.005825	62.027	195	1.035873	60.227
100	1.006822	61.965	200	1.037819	60.114
105	1,007905	61.899	205	1.039798	60.000
110	1.009032	61.829	210	1.041809	59.884
115	1.010197	61.758	212	1.042622	59.838
120	1.011442	61.682	...	....	......

VOLUME AND WEIGHT OF DRY AIR.

At different temperatures, under a constant atmospheric pressure of 29.92 inches in the barometer, the volume of 32° being unit.

Dry air expands or contracts uniformly 0.0020825 its volume per degree Fahr. in difference of temperature.

Reference: — (Contents in cubic ft. and lbs.)

V = Volume at temp. T.
v = Volume at temp. t.

$$V = v\left\{\frac{T-t}{480} + 1\right\}; \quad T-t = \frac{480\,(V-1)}{v}.$$

W = Weight per cubic ft. at 32° = 0.0807.
w = Weight per cubic ft. at T.

$$w = \frac{W}{V}.$$

EXAMPLE: —

v = 20 cubic ft. of air at 40° = t, is to be heated to 80° = T; what is the volume V?

$$V = 20 \left\{ \frac{80-40}{480} + 1 \right\} = 21.660 \text{ cubic ft. (the answer).}$$

NOTE.—In the following table V = 1, and t = 32°.

VOLUME AND WEIGHT OF DRY AIR.

T°	V	w	T°	V	w
0	0.935	0.0864	275	1.495	0.0540
12	0.960	0.0842	300	1.546	0.0522
22	0.980	0.0824	325	1.597	0.0506
32	1.000	0.0807	350	1.648	0.0490
42	1.020	0.0791	375	1.689	0.0477
52	1.041	0.0776	400	1.750	0.0461
62	1.061	0.0761	450	1.852	0.0436
72	1.083	0.0747	500	1.954	0.0413
82	1.102	0.0733	550	2.056	0.0384
92	1.122	0.0720	600	2.150	0.0376
102	1.143	0.0707	650	2.260	0.0357
112	1.163	0.0694	700	2.362	0.0338
122	1.184	0.0682	800	2.566	0.0315
132	1.204	0.0671	900	2.770	0.0292
142	1.224	0.0659	1000	2.974	0.0268
152	1.245	0.0649	1100	3.177	0.0254
162	1.265	0.0638	1200	3.381	0.0239
172	1.425	0.0628	1500	3.993	0.0202
182	1.306	0.0618	1800	4.605	0.0175
192	1.326	0.0609	2000	5.012	0.0161
202	1.347	0.0600	2200	5.420	0.0149
212	1.367	0.0591	2500	6.032	0.0133
230	1.404	0.0575	2800	6.644	0.0121
250	1.444	0.0559	3000	7.051	0.0114

HEATING WITH HOT WATER.

GENERAL PRINCIPLES.

In a hot water apparatus, the temperature of the water in the boiler never exceeds 212°, the mean temperature in the heating pipes being from 150 to 200°; the temperature in pipes is increased or diminished by stop cocks, for controlling the velocity or volume of water passing through the pipes in a given time.

Air vents or cocks must be provided, as water evolves air when its temperature rises to the boiling point. The air collects at the highest points of the apparatus, and at places where the horizontal flow pipe dips, and where the risers in the return pipe connect with the horizontal, for instance at points a, in Fig. 20.

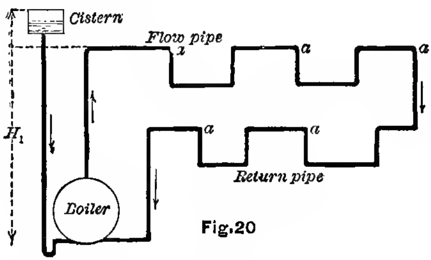


Fig. 20

The higher the ascending and descending pipes, or the greater the difference between their temperature, the more rapid will be the circulation.

To increase the difference of temperature between the ascending and descending pipes, either increase the quantity of pipe, so that the water will flow a greater distance, or decrease the diameter, so that they will part with more heat. The specific gravity in pipe h (Fig. 21), must be greater than in pipe h_1, to produce circulation; the greater amount of cooling should

take place in the coils above the dotted line a, or bottom of boiler. (See Fig. 21.)

The hot water should rise to the highest point in the most direct way, so that the pipes give out the heat in returning to the boiler; otherwise a reversal of the circulation might occur.

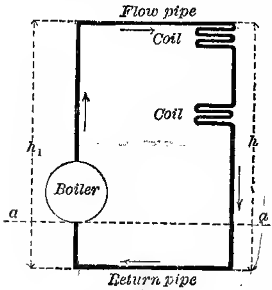


Fig. 21

All closed boilers must be provided with a supply cistern, located above the highest point of the apparatus; it should be proportioned to contain about $\frac{1}{30}$ of the whole quantity of water in the pipes and boiler.

The pressure in the boiler and pipes increases only with the height of cistern above the boiler or lowest pipe.

The pipe from cistern should lead to the bottom of boiler, or into the return pipe, and bent in the shape of a syphon, see Fig. 20, to prevent the escape of heat or vapor from the boiler.

The effect is the same, whether there are more flow than return-pipes, or *vice versa*; each range will act separately, having a velocity of circulation peculiar to itself; they may return to the boiler separately, or united in a main pipe.

Horizontal leading pipes should be larger in proportion to the branch pipes than vertical leading pipes, because the flow of hot water is more rapid in vertical than in horizontal pipes.

Vertical leading pipes, running through several stories, should decrease in diameter as they ascend, or be supplied with cocks to equalize the flow; the hot water tending to rise to the highest, leaving the pipes in lower stories comparatively cold.

When coils are somewhat distant from each other, the connecting pipe should be smaller than the pipes in coils.

Pipes must be kept scrupulously clean and free from shavings, dirt, etc., or circulation will be retarded.

Expansion and contraction in the pipes must be provided for.

The advantages of hot water over steam are: less cost of fuel; no danger of explosion; requires less repairs; the temperature in pipes is maintained 6 to 8 times longer than in steam pipes, after the fire is extinguished; and another great advantage is, that the temperature in the pipes can be increased or dimished, by reducing the flow of the hot water.

DIAMETER OF PIPES—BORE.

Connection Pipes to Coils.

UPPER STORY OF A BUILDING, DIRECT RADIATION.

COIL SURFACE.	DIAM. OF PIPE.	SECTIONAL AREA.
60 sq. ft. or less.	¾ inch.	0.44 sq. inch.
100 " "	1 "	0.78 "
175 " "	1¼ "	1.22 "
250 " "	1½ "	1.76 "
600 " "	2 "	3.14 "

For each successive lower story, increase the cross sectional area of pipe by 15% over that in the preceding story.

BASEMENT OR CELLAR OF A BUILDING, INDIRECT RADIATION.

COIL SURFACE.	DIAM. OF PIPE.	SECTIONAL AREA.
75 sq. ft. or less.	1 inch.	0.78 sq. inch.
140 " "	1¼ "	1.22 "
225 " "	1½ "	1.76 "
500 " "	2 "	3.14 "

The sectional area of a branch pipe must equal the area of all the connections, and the area of a main pipe must equal the area of all branches.

The return-pipes to a coil or series of coils must have the same diameter as the respective flow-pipes; for example see Fig. 22.

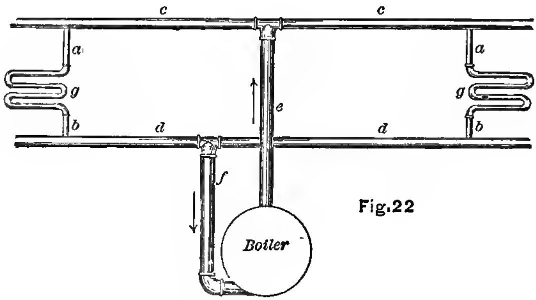


Fig. 22

REFERENCE :—Fig. 22.

a = Flow connection pipes, 1 in. diam.
b = Return connection pipes, 1 in. diam.
c = Flow branch pipe, 1½ in. diam.
d = Return branch pipe, 1½ in. diam.
e = Flow main pipe, 2 in. diam.
f = Return main pipe, 2 in. diam.
g = Coils.

Pipes in Coils.—The diameter of pipes in coils should be:

When coil is in contact with the incoming air, which is intended to be warmed, the diameter should not be less than 2½ inches; when the coil is a direct radiator, not in contact with cold air, the diameter should not be less than 1¼ inch.

FLOW OF HOT WATER IN PIPES.

The circulation of water in pipes of a hot water apparatus is caused by the difference in weight of two columns of water, connected at top and bottom, see Fig. 23; one column being

continually heated, and the water expanded, thereby producing a difference in weight, and in consequence a circulation.

The velocity increases with the temperature in the rising column, and the loss of temperature in the return column; it is reduced by the friction in the pipes and elbows.

The friction in pipes decreases with the velocity, and, in a less degree, with the increase in diameter of the pipes; it also decreases with the temperature of the water, up to certain limits; this, however, is not considered in the following:

Let Fig. 23 represent a boiler with main circulating pipes.

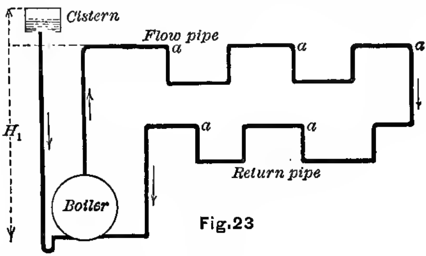


Fig. 23

REFERENCE:—(All dimensions in ft. and lbs.) See Fig. 23.

Let H = Effective head of water, producing motion.

H_1 = Height of water above lowest point of return pipe.

t = Temp. of water in boiler = 210°.

t_1 = Temp. of water as it returns to boiler.

t_2 = Average temp. of water in pipes = $\frac{t+t_1}{2}$.

T = Temp. of air in contact with pipes.

w = Weight of water at the temp. t.

w_1 = Weight of water at the temp. t_1.

Q = Quantity of water to be moved, per second.

q = Contents of one lineal foot of pipe.
u_1 = Units of heat given out by the pipe per lineal foot, per hour.
l = Length of pipe.
A = Sectional area of pipe.
d = Diameter of pipe.
f = Friction in straight run of pipe.
f_1 = Friction in elbows.
v = Velocity of water in pipe in ft. per second.
g = Accelerated gravity = 32.166 ft. per second.
u = Units of heat given out per sq. ft. per hour, as per table, page 39.
n = Number of elbows.
w_2 = Weight of water at temp. t_2

$$H = H_1 - \frac{H_1 w}{w_1} = \left\{ 1 + nf_1 + f\frac{l}{d} \right\} \frac{v^2}{2g}; \qquad H_1 = \frac{H}{1 - \frac{w}{w_1}};$$

$$v = \frac{\sqrt{2gh}}{\sqrt{1+nf_1+f\frac{l}{d}}} = \frac{Q}{A} = \frac{4Q}{\pi d^2} = 1.2732\frac{Q}{d^3} = \frac{u_1 l}{qw_2(t_2-T)};$$

$$Q = \frac{\pi d^2}{4} v = 0.7854 d^2 v;$$

$$u_1 = ud\,3.1416;$$

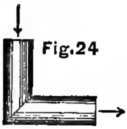
$$q = 0.7854 d^2;$$

$$A = 0.7854 d^2;$$

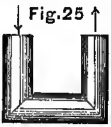
$$t_1 = 2t_2 - t;$$

$$f = 0.01439 + \frac{0.017152}{\sqrt{v}}.$$

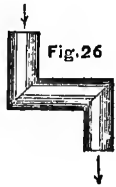
FRICTION IN ELBOWS OR CONNECTIONS.

I. 
Fig. 24

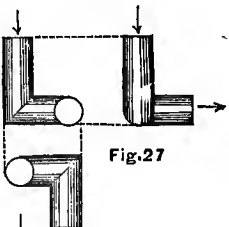
$f_1 = 0.984.$

II. 
Fig. 25

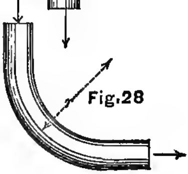
$f_1 = 0.984.$

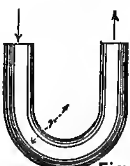
III. 
Fig. 26

$f_1 = 1.968.$

IV. 
Fig. 27

$f_1 = 1.456.$

V. 
Fig. 28

VI. 
Fig. 29

$$f_1 = 0.131 + 1.847 \left\{ \frac{a}{r} \right\}^{\frac{7}{2}}$$

$$a = \frac{d}{2}.$$

When $r = 2a$, $f_1 = 0.294$.

When $r = 10a$, $f_1 = 0.131$.

VII.

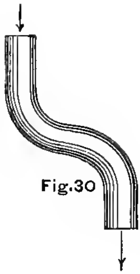


Fig.30

$$f_1 = 2\left\{0.131 + 1.847\left(\frac{a}{r}\right)^{\frac{7}{2}}\right\};$$

$$a = \frac{d}{2}.$$

VALUES OF f_1, FOR ELBOWS V AND VI.

When $\frac{a}{r}$ =	0.1	0.2	0.3	0.4	0.5
f_1 =	0.131	0.138	0.158	0.206	0.294
when $\frac{a}{r}$ =	0.6	0.7	0.8	0.9	1.0
f_1 =	0.440	0.661	0.977	1.408	1.978

Coefficient of Friction, f, *for Given Velocities*, v.

Velocity in feet per Second.	f	Velocity in feet per Second.	f	Velocity in feet per Second.	f	Velocity in feet per Second.	f
0.01	0.1859	0.19	0.0536	0.37	0.0425	0.75	0.0340
0.02	0.1356	0.20	0.0526	0.38	0.0421	0.80	0.0334
0.03	0.1133	0.21	0.0517	0.39	0.0417	0.85	0.0329
0.04	0.1001	0.22	0.0508	0.40	0.0414	0.90	0.0323
0.05	0.0893	0.23	0.0500	0.41	0.0410	0.95	0.0318
0.06	0.0843	0.24	0.0493	0.42	0.0406	1.00	0.0314
0.07	0.0790	0.25	0.0486	0.43	0.0404	1.10	0.0306
0.08	0.0750	0.26	0.0479	0.44	0.0401	1.20	0.0299
0.09	0.0715	0.27	0.0473	0.45	0.0398	1.30	0.0293
0.10	0.0685	0.28	0.0467	0.46	0.0395	1.40	0.0287
0.11	0.0660	0.29	0.0461	0.47	0.0393	1.50	0.0283
0.12	0.0638	0.30	0.0456	0.48	0.0390	1.60	0.0279
0.13	0.0624	0.31	0.0451	0.49	0.0388	1.70	0.0274
0,14	0.0601	0.32	0.0446	0.50	0.0385	1.80	0,0271
0.15	0.0586	0.33	0.0442	0.55	0.0374	1.90	0.0267
0.16	0.0585	0.34	0.0437	0.60	0.0364	2.00	0.0264
0.17	0.0556	0.35	0.0432	0.65	0.0355	...	.....
0.18	0.0547	0.36	0.0428	0.70	0.0348	...	.....

$$f = 0.01439 + \frac{0.017152}{\sqrt{v}}.$$

EXAMPLES :—

A pipe 500 ft. long, 4 in. = 0.33 ft. diameter, shall have an average temperature $t_2 = 150°$, the temperature of air and walls surrounding it to = 70°; what is the velocity v, head H, and column H_1?

$l = 500.$

$d = 0.33.$

u, as per table = 178.87.

$t = 210°$; $T = 70°$.

w_2, at the temp. $t_2 = 61.2$.

$u_1 = ud3.1416 = 178.87 \times 0.33 \times 3.1416 = 185.44$ units per hour per lineal ft. of pipe.

$q = 0.7854d^2 = 0.7854 \times 0.33^2 = 0.088$ cubic ft.

$$v = \frac{u_1 l}{q w_2 (t_2 - T)} = \frac{185.44 \times 500}{0.088 \times 61.2(150-70)} = \frac{92720}{430.85}$$

$$= 215.2 \text{ ft. per hour} = \frac{215.2}{3600} = 0.06 \text{ per second.}$$

$$H = \left\{ 1+f+\frac{l}{d} \right\} \frac{v^2}{2g} = \left\{ 1+0.0843\frac{500}{0.33} \right\} \frac{0.06^2}{2 \times 32.166}$$

$$= 128.73\,\frac{0.0036}{64.33} = 0.0072 \text{ ft.}$$

$t_1 = 2t_2 - t = 2 \times 150 - 210 = 300 - 210 = 90°$; and w_1, for 90° = 62.05; w, for 210° = 59.83.

$$H_1 = \frac{H}{1 - \frac{w}{w_1}} = \frac{0.0072}{1 - \frac{59.83}{62.05}} = \frac{0.0072}{0.036} = 0.2 = 2.4 \text{ inches.}$$

DIMENSIONS OF BOILERS, GRATES, ETC.

REFERENCE :—

A = Total area of heating surface of boiler, in square feet.
A_1 = Area of grate, in square feet.
a = Area of boiler, directly heated, in square feet.
a_1 = Area of boiler, indirectly heated (flues), in square feet.
a_2 = Sectional area of boiler.
a_3 = Sectional area of flues (all).
D = Diameter of boiler.
d = Diameter of flue.
l = Length of boiler or flues.
n = Number of flues in boiler.
K = Number of pounds of coal consumed per hour.
U = Total units of heat given out by the coils or radiators, per hour.
u = Units of heat given out by 1 lb. of coal, generally = 6000 (effective).

$$A = \frac{U}{600}; \qquad A_1 = \frac{K}{10}; \qquad K = \frac{U}{u}; \qquad a = \frac{D l 3.1416}{2};$$

$$a_1 = d l n 3.1416; \qquad a_2 = a_3 2.5; \qquad a_3 = a_2 0.4;$$

$$D = \frac{a 2}{l 3.1416}; \qquad d = \frac{a_1}{l n 3.1416}; \qquad l = \frac{a_1}{d n 3.1416};$$

$$n = \frac{a_1}{d l 3.1416}.$$

The flues in boiler are generally 2 to 4 inches diameter; the sizes used varying with the length of boiler or flue, and the quality of coal designed to be used, as follows:

LENGTH OF BOILER, IN FEET.	DIAMETER OF FLUES, IN INCHES.	
	Soft coal.	Hard coal.
8 or less	2	2
10	2½	2
12	3	2½
16	4	3

Distance between flues, or shell and flue, 1 to 1½ inch.

EXAMPLE :—

A hall, Fig. 7, 100 feet long, 80 feet wide, and 40 feet high, the surrounding walls 20 inches thick; the ceiling flat, covered by a hipped roof; the two opposite sides of the hall are provided with windows, 8 to each side, 4 feet wide and 14 feet high.

The hall to be heated by indirect radiation, located in the basement, under the hall floor. The heating apparatus to be a "hot water," the temperature in pipes not to exceed 160°; the boiler to be a "cylindrical flue" boiler.

The hall to be occupied by 300 persons, for twelve hours each day, the vitiation not to exceed 0.06%.

Ventilation to be the vacuum movement, by means of air aspirating chimney; the currents in hall to be upward and not to exceed 1.5 ft. per second.

Loss of Heat per Hour.

All sides of the building exposed, walls of brick; see formulas, page 36.

$$U = \frac{l_2 c q(T - T_1)}{c(2l_2 + r) + e l_2 q}$$

$$= \frac{0.4912 \times 4.83 \times 1.227(70 - 40)}{4.83(2 \times 0.4912 + 0.7358) + 20 \times 0.4912 \times 1.227}$$

$$= \frac{2.911 \times 30}{4.83(0.9824 + 0.7358) + 12.054} = \frac{87.33}{8.299 + 12.054}$$

$$= \frac{87.33}{20.353} = 4.29 \text{ per sq. ft.}$$

$l_2 = 0.09824 \times 5 \times 1 = 0.4912.$

$c = 4.83.$

$q = r + l_2 = 0.7358 = 0{,}4912 = 1.227.$

$r = 0.7358.$

$e = 20$ inches.

$T = 70°.$

$T_1 = 40°.$

Windows ¼ in. thick glass; see formulas, page 36.

$$U = q(T - t_4) = 1.086(70 - 55) = 16.29 \text{ per sq. ft.}$$

$$t_4 = \frac{T + T_1}{2} = \frac{70 + 40}{2} = 55°.$$

$$r = 0.5948.$$

$$q = r + l_2 = 0.5948 + 0.4912 = 1.086.$$

Incoming fresh air; see formulas, page 39.

$$U = Qnws\,(T - T_1) = Vws(T - T_1)$$
$$= 1032000 \times 0.079 \times 0.238(70 - 40) = 582109.92.$$

$$Q = 100 \times 80 \times 40 = 320000.$$

$V = 16 \times 215 \times 300 = 1032000$, or 3440 cubic feet for each occupant, per hour.

$$n = \frac{V}{Q} = \frac{1032000}{320000} = 3.2.$$

$$s = 0.238.$$

w, at 40° = 0.079 lbs.

Total Loss of Heat.

From walls.

Area, $(100 + 100 + 80 + 80)40 - 896 = 13504$;

$$U = 13504 \times 4.29 = 57932.16$$

From windows.

Area, $14 \times 4 \times 16 = 896$;

$$U = 896 \times 16.29 = 14595.84.$$

From incoming fresh air.

For 300 occupants	582109.92.
Total	654637.92

Heating Surface H.

For indirect radiation, when the temperature of radiator shall not exceed 160°, 1 square foot of hot water pipe, for air moving, gives 126.13 units per hour.

Number of square ft. of heating surface $= \frac{654637.92}{126.13} = 5190$,

or lineal ft. of 4 in. diam. pipe $= \frac{654637.92}{126.13 \times 0.33 \times 3.1416} = 4956$.

Cubic ft. of air heated, per sq. ft. of surface $= \frac{320000}{5190} = 61.6$.

Size of Boiler.

$$A = \frac{654637.92}{600} = 1091.06 \text{ sq. ft.}$$

Quantity of Coal Consumed per Hour, for Boiler.

$$K = \frac{U}{6000} = \frac{654637.92}{6000} = 109.10 \text{ lbs. per hour.}$$

Area of Grate Surface.

$$A_2 = \frac{K}{10} = \frac{109.10}{10} = 10.91 \text{ sq. ft.}$$

Size of Openings in Floor and Ceiling.

Velocity of current, 1.5 ft. per second; total area $= \frac{1032000}{1.5 \times 3600}$ $= 154$ sq. ft., or 154 openings 1 ft. square.

Aspirating Chimney.

Assumed velocity of air in shaft = 10 feet per second.

Height of chimney, 80 feet.

Sectional area $= A = \dfrac{V}{v\,3600} = \dfrac{1032000}{36000} = 28.7$, or a square $= \sqrt{28.7} = 5.35$, say 5.4 feet.

The temperature necessary in the shaft to produce a velocity of 10 ft. is,

$$t_3 = \frac{v^2(1 + et)(1 + f\frac{l}{d} + f_1)}{2ghe} - (t_1 - t);\ \text{in which}$$

$t = 40°$; $t_1 = 70$; $e = 0.00208$; $g = 32.166$; $l = 200$ ft.; $h = 80$ ft.; $f = 0.05$, and f_1 for 4 square elbows $= 1.5 \times 4 = 6.0$; $d = 5.4$. Hence

$$t_3 = \frac{10^2(1 + 0.00208 \times 40)\,(1 + 0.05\,\frac{200}{5.4} + 6)}{2 \times 32.166 \times 80 \times 0.00208} - (70° - 40)$$

$$= \frac{100 \times 1.0832 \times 8.85}{10.72} - 30 = \frac{958.63}{10.72} - 30 = 89 - 30$$

$$= 59°.$$

Quantity of coal necessary to produce this temperature,

$$K = \frac{t_3\,s\,W}{u\,\%} = \frac{59 \times 0.238 \times 81528}{5400} = 211 \text{ lbs. per hour.}$$

If the plenum movement were adopted, using a Rittinger fan, the horse-power required would be

$$Hp = 0.38\,Vh = \frac{0.28 \times 1032000 \times 0.14}{3600} = \frac{54902.4}{3600} = 15.2;$$

and allowing 8 lbs. of coal per horse-power, which is ample,

$$K = 15.2 \times 8 = 121.6 \text{ lbs. per hour.}$$

HEATING WITH STEAM.

GENERAL PRINCIPLES.

In heating with steam, the pipes forming radiators, are generally smaller in diameter than those for hot water, the temperature increasing with the pressure of steam in the boiler.

The temperature in pipes should never be below 212°; otherwise the steam rapidly condenses to water, to get rid of which the pipes must be inclined so that the water may easily flow back to the boiler, or drip pipes communicating with the bottom of radiators and feed pipe; the pipes should be so inclined, that the water will flow in the same direction that the steam does.

The steam leaves the boiler at the top, and the water from the condensed steam returns at the bottom.

The fire under the boiler must be kept brisk, or the heating effect ceases rapidly.

A cock should be placed between the boiler and heating pipes, on opening which the steam drives the air in the pipes before it, to an outlet or air cock that must be provided at the end of the pipe and at the bottom of radiators. It is sometimes necessary to resort to air pumps for extracting the air in the pipes, especially when the coils are on different levels.

The boiler should be so proportioned, that it will evaporate as much water as is condensed in the pipes; and supplied with water by a stone float valve, the cistern being sufficiently high above the boiler that the pressure of water will overcome the pressure of steam in the boiler; when practicable, force pumps or injectors are used, these appliances require no elevated tank or cistern.

The boiler must be supplied with safety valves, steam gauges, water gauges, and also gauge cocks, to indicate the pressure of steam and height of water. A blow-off cock, at the bottom of

boiler, is also required, for supplying and cleaning the boiler every week or so, depending on the quality of the feed water.

Steam possesses an advantage over hot water, in the ease of application, where great inequalities and frequent alterations of level occur, and particularly where the boiler must be placed higher than the places to be heated. For buildings occupied at intervals, steam is more effective than hot water, in its rapid generation of heat; so also for buildings using power boilers, when of sufficient size to supply both engine and radiators. The original cost of steam apparatus is somewhat less than hot water apparatus.

Expansion and contraction in the pipes must be provided for. The apparatus must receive constant care and attention, the fire must be kept brisk, the water at the proper level, and the steam not allowed to generate too fast, endangering perhaps the safety of the boilers.

DIAMETER OF PIPES — BORE.

When pressure of steam is not above 15 lbs. per sq. inch (saturated steam).

Connection Pipes to Coils — Direct or Indirect Radiation.

COIL SURFACE.	DIAM. OF PIPE.	SECTIONAL AREA.
25 sq. ft or less.	3/4 inch.	0.44 sq. inch.
40 " "	1 "	0.78 "
80 " "	1 1/4 "	1.22 "
160 " "	1 1/2 "	1.76 "
250 " "	2 "	3.14 "

Flow Pipes.

The sectional area of a branch pipe must equal the area of all connection pipes, and the sectional area of a main pipe must equal the area of all branch pipes.

Return Pipes.

The sectional area of the return pipes from a coil, or series of coils, must be one size less than the respective flow pipe to the coils. Drip pipes should connect with all risers (vertical flow pipes), the water being taken into the return pipes or boiler.

The sectional area of main pipes should be reduced as soon as practicable.

Coils.

Diameter of pipes in coils, from $\frac{3}{4}$ to 2 inches.

DIMENSIONS OF BOILERS, FURNACES, AND FITTINGS.

Area of Fire Grate.

With chimney draught = 0.1 to 0.04 sq. ft., per lb. of fuel per hour.

With fan or blast = 0.04 to 0.01 sq. ft., per lb. of fuel per hour.

Sectional Area of Flues or Tubes.

From $\frac{1}{7}$ to $\frac{1}{5}$ area of grate.

Capacity of Boiler.

Steam and water space = heating surface × from 3 to $1\frac{1}{2}$ foot, in cylindrical and flue boilers; and from 1 to 0.5 foot, in tubular boilers; and about 0.1 foot, in water-tube boilers.

Capacity of Furnace, Tubes, and Flues

From 6 to 8 ft. × area of grate.

Area of Safety Valves in Square Inches.

The greatest weight of water to be actually evaporated in lbs. per hour × 0.006.

Steam and Water Space.

Steam space = 0.4 total space.

Water " = 0.6 " "

Water should stand not less than 4in. above heating flues.

The evaporating power of boiler should be 30% larger than the quantity of water condensed in the pipes.

The temperature of steam in pipes diminishes with the distance from the boiler.

The horse power of a boiler is equal to the number of cubic feet of water evaporated per hour.

When steam above 15 lbs. pressure is used, the boiler should be provided with a steam drum or dome = 1/8 steam space given above, so that the steam space = 0.525 total space.

REFERENCE :—

A = Total area of heating surface of boiler, in square feet.

A_1 = Area of grate in square feet.

a = Area of boiler, directly heated, in square feet.

a_1 = Area of boiler, indirectly heated (flues), in square feet.

a_2 = Sectional area of boiler.

a_3 = Sectional area of flues (all).

D = Diameter of boiler.

d = Diameter of flue.

l = Length of boiler or flue.

n = Number of flues in boiler.

K = Number of pounds of coal consumed, per hour.

U = Total units of heat given out by coils or radiators, per hour.

u = Units of heat given out by 1 lb. of coal (effective).

e_1 = Units of evaporation = 966 units of heat required to evaporate 1 lb. of water, under one atmosphere.

W_1 = Total quantity of water, condensed in pipes, coils, etc., in lbs., per hour.

w_1 = Pounds of water at 212°, evaporated by 1 lb. of fuel.

Hp = Horse power of boiler.

$$A = \frac{U}{1200}; \quad A_1 = 0.1K \text{ to } 0.04K \text{ for chimney draught};$$

$$a = \frac{Dl3.1416}{2}; \quad a_1 = dln3.1416; \quad a_2 = a_3 5.0; \quad a_3 = a_2 0.2;$$

$$D = \frac{a2}{l\,3.1416}; \quad d = \frac{a_1}{ln\,3.1416}; \quad l = \frac{a_1}{nd3.1416};$$

$$n = \frac{a_1}{dl\,3.1416};$$

$$W_1 = \frac{U}{e_1}; \quad w_1 = \frac{u}{e_1}; \quad K = \frac{W_1}{w}; \quad Hp = \frac{W_1}{62.5}.$$

NOTE.—The same proportions of flues and distances between them, given for hot water boilers, apply also to steam boilers.

TEMPERATURE OF STEAM IN BOILER, AND PRESSURE PER SQUARE INCH.

REFERENCE :—

I = Inches of mercury that balance the steam.
P = Pressure of steam per square inch in boiler, in lbs.
T = Temperature of steam in boiler.
t = Mean temperature of steam in pipes.

$$I = \left\{ \frac{T}{180} + 0.58407 \right\}^6 = P\,2.0376;$$

$$P = \left\{ \frac{T}{202} + 0.52 \right\}^6 = I\,0.48875;$$

$$T = \left\{ \sqrt[6]{P} - 0.52 \right\} 202; \quad t = \frac{19}{20} T.$$

NOTE.—These formulas are approximate only, but agree quite well with actual results. See table, page 64.

TEMPERATURE OF STEAM IN PIPES, t=	TEMPERATURE OF STEAM IN BOILER, T=	PRESSURE PER SQUARE INCH IN BOILER, P= Pressure of Atmosphere, 14.73. Included.	Excluded.
210°	221.0°	17.67	2.94
220	231.5	21.38	6.65
230	242.0	25.75	11.02
240	256.5	32.89	18.16
250	263.0	36.58	21.85
260	273.5	43.31	28.58
270	284.0	51.04	36.31
280	295.0	60.25	45.52
290	305.0	69.77	55.04
300	315.0	80.98	66.25

EXAMPLE :—

Required, the dimensions of steam boiler, quantity of pipe, etc., to heat the hall, as per example, page 55.

External temp., $= 40°$.

Temp. of pipes, mean 230°.

Temp. of hall $= 70°$.

Temp. of boiler $= \frac{20}{19} 230 = 242°.1$.

Total pressure in boiler for $242° = 26$ lbs. per square inch, in round numbers.

Total units of heat to be supplied to hall $= 654637.92$ per hour.

Units of heat per square foot of pipe, per hour, by contact for indirect radiation $= 256.58$.

Number of square feet of pipe $= \frac{654637.92}{256.58} = 2551.4$.

Lineal ft. of 2 in. diam. pipe $= \frac{2551.4}{0.166 \times 3.1416} = 4892$.

Cubic ft. of air heated per sq. ft. of surface $= \frac{320000}{2551.4} = 125$.

Size of Boiler.

$$W_1 = \frac{654637.92}{966} = 677.6\,; \qquad Hp = \frac{W_1}{62.5} = \frac{677.6}{62.5} = 11$$

$$A = \frac{654637.92}{1200} = 545.5\,;$$

$$w_1 = \frac{6000}{966} = 6.2\,; \quad K = \frac{677.6}{6.2} = 109.3\,;$$

$$A_1 = 0.1 \times 109.3 = 10.9.$$

3**

$$\frac{2557}{11} = 232$$

232 sq ft. surface per 1 HP

COMBUSTION OF FUEL.

Combustion consists in the rapid combination of substances with oxygen, generally carbon and hydrogen, the result being the development of heat and light.

The following are the principal combustibles used in the arts, and their chemical composition, according to Péclet :

Substance.	Sign.	Coal.	Coke.	Wood.		
				Perfectly dry.	Ordinary state.	Charcoal.
Carbon	C	0.812	0.850	0.510	0.408	0.930
Hydrogen	H	0.048	....	0.053	0.042	....
Oxygen	O	0.054	....	0.417	0.334	....
Nitrogen and Sulphur	N	0.031	....	....	....	....
Water.............	W	....	....	....	0.200	....
Ashes	A	0.055	0.150	0.020	0.016	0.070
Total	..	1.000	1.000	1.000	1.000	1.000

The following substances consist of :—

1 lb. of Carbonic Acid consists of $\frac{C_1}{C_1+2O_1}=0.2727$ lbs. of carbon.

" " " $\frac{2O_1}{C_1+2O_1}=0.7273$ " oxygen.

" Water " $\frac{H_1}{O_1+H_1}=0.111$ " hydrogen.

" " " $\frac{O_1}{O_1+H_1}=0.889$ " oxygen.

" Air " $\frac{O_1}{2N_1+O_1}=0.222$ " oxygen.

" " " $\frac{2N_1}{2N_1+O_1}=0.778$ " nitrogen.

In which the chemical equivalents are :—

$$\begin{aligned} \text{of } C_1 &= 75.00; \\ H_1 &= 12.50; \\ N_1 &= 175.00; \\ O_1 &= 100.00. \end{aligned}$$

To estimate the theoretical units of heat in lb. of fuel :—

Distinguish the constituents into carbon, hydrogen, oxygen, and refuse, as per table, page 66. The quantity of each being in fractions of a lb. analyzed.

$$U = 14500\,C + 62000\left\{H - \frac{O}{8}\right\}.$$

Net weight of air chemically necessary for the complete combustion of a unit of weight of fuel, theoretically :—

REFERENCE :—

W = Lbs. of air required.
w = Weight of a cubic ft. of air.
V = Volume in cubic ft.

$$W = 12\,C + 36\left(H - \frac{O}{8}\right);$$

$$V = \frac{W}{w}.$$

In most cases, additional air is required to sufficiently dilute the products of combustion, the increase being in the ratio of 1½ to 1, or 2 to 1, of the theoretical value.

EFFICIENCY OF FURNACES AND BOILERS, APPROX.

REFERENCE : —

A_3 = Intended number of square feet of heating surface (meaning both direct and indirect), per lb. of fuel per hour.

E = Efficiency of furnace or boiler.

U = Theoretical units of heat in a lb. of fuel.

U_1 = Effective units of heat in a lb. of fuel.

. . . . $U_1 = U E.$

When the draught is produced by a chimney :—

$$E = \frac{A_3}{A_3 + 0.5} \times \frac{11}{12}.$$

When the draught is produced by a fan or blast :—

$$E = \frac{A_3}{A_3 + 0.3} \times \frac{11}{12}.$$

EXAMPLES OF EFFICIENCY ($U = 13000$).

	A_3	E	U_1
Small heating surface	0.50	0.46	5980
Ordinary heating surface in tubular boilers	0.75	0.55	7150
	1.00	0.61	7930
	1.25	0.65	8450
	1.50	0.69	8970
	2.00	0.73	9490
Water tube and cellular boilers	3.00	0.79	10270
	6.00	0.84	10920

The efficiency is liable to be diminished from 0.2 to 0.5 of its proper value, through unskillful firing.

PROPORTION OF SMOKE CHIMNEYS.

REFERENCE :—

A = Sectional area in square ft.
V = Volume of smoke delivered in cubic ft.
K = Pounds of coal consumed per hour.
h = Height of chimney in ft.
v = Velocity of smoke in ft., per second.
t = External temperature, average 50°.
t_1 = Internal temperature, average 550°.

$$v = 0.08\sqrt{(t_1 - t)h};$$

$$A = \frac{12.5\,V}{\sqrt{(t_1 - t)h}};$$

$$V = Av = A\,0.08\sqrt{(t_1 - t)h};$$

$$h = \frac{156}{t_1 - t}\left\{\frac{V}{A}\right\}^2.$$

Generally, allowing 600 cubic ft. of smoke for 1 lb. of coal,

$$A = 0.128\,\frac{K}{\sqrt{h}}, \text{ and } h = 0.01638\left\{\frac{K}{A}\right\}^2.$$

HYGROMETRY.

HUMIDITY OF AIR.

Air, in a free or normal state, contains more or less vapor of water. When this air is passed into rooms, over heated bodies and its temperature is raised, the quantity of moisture it contains is not diminished, but the relative humidity is lessened; or, in other words, its capacity for containing moisture is increased. When the air is cold, it may contain very little vapor, and yet be moist; and on the contrary, when it is warm, it may contain a considerable quantity of vapor, and be very dry.

In summer, there is usually more aqueous vapor in the air than in winter, yet it is less moist, the air being farther from its point of saturation, by reason of the higher temperature.

The *degree* or *point of saturation*, or *hygrometric state*, is the ratio of the quantity of aqueous vapor, actually present in the air, to that which it would contain were it saturated, the temperature being the same.

A body, gradually cooling in the ambient air to a lower temperature, will in time be at a temperature when the vapor in the air, being condensed, will be precipitated on the surface of the body in the form of dew; this temperature is called the *dew point.*

To determine the humidity of air, Wet and Dry Bulb Hygrometers are used, the dew point being obtained by noting the temperatures of the wet and dry bulbs, and inserting the values in certain formulas, given below.

The methods generally used to hydrate or moisten the air in rooms to the desired ratio or percentage of saturation, are:

by placing shallow vessels, containing water, in the hot air ducts, the evaporation being increased by the application of heat to the vessel; or copper cylinders, placed horizontally and transversely across the duct, heated internally with steam or hot water, vapor being formed by the evaporation of drops or jets of water falling on the top of the cylinder; or, for summer, sprays of cold water ejected through small holes in a pipe or series of pipes; in each case the air passes through, and takes up a certain amount of vapor, the quantity being regulated by adjusting the flow of water or temperature of the heat producing evaporation.

REFERENCE:—

T = Temperature of air.
t = Temperature of the *dew* point.
t_1 = Temperature of the *wet* bulb.
t_2 = Temperature of the *dry* bulb.
I = Height of barometer, balancing the air (= 30 inches generally).
I_1 = Height of barometer, balancing the dry air (of the mixture.)
p = Elastic force of vapor at the temperature T, in inches of mercury.
p_1 = Elastic force of vapor at the temperature t, in inches of mercury.
W = Weight of the vapor, in lbs., in a cubic foot of dry air mixed with vapor.
w = Weight of a cubic foot of dry air, in lbs., at the temperature T.
w_1 = Weight of the dry air, in lbs., in a cubic foot of saturated air.
w_2 = Weight of the vapor, in lbs., in a cubic foot of saturated air.
w_3 = Weight of the air and vapor, in lbs., in a cubic foot of saturated air.

w_4 = Weight of vapor in 1 lb. of air.
w_5 = Weight of dry air in lbs., mixed with 1 lb. of vapor.
R = Ratio of humidity to saturation.

$$w_1 = \frac{w\,I_1}{I}; \quad w_2 = \tfrac{5}{8}\frac{w\,p}{I}; \quad w_3 = w_1 + w_2;$$

$$w_4 = \frac{w_2}{w_1}; \quad w_5 = \frac{w_1}{w_2}; \quad W = w_2 R;$$

$$I_1 = I - p; \quad R = \frac{p_1}{p}; \quad p = \frac{p_1}{R}; \quad p_1 = p\,R;$$

$$t = t_2 - (t_2 - t_1)k;$$

$$w = \frac{0.0807}{\frac{458.4 + T}{490.4}} \times \frac{29.92}{I}.$$

VALUES OF k.

TEMPERATURE OF DRY BULB.	k	TEMPERATURE OF DRY BULB.	k	TEMPERATURE OF DRY BULB.	k
Below 24°	8.5	From 31°– 32°	3.7	From 55°– 60°	1.9
From 24°– 25°	6.9	" 32 – 33	3.3	" 60 – 65	1.8
" 25 – 26	6.5	" 33 – 34	3.0	" 65 – 70	1.7
" 26 – 27	6.1	" 34 – 35	2.8	" 70 – 75	1.7
" 27 – 28	5.6	" 35 – 40	2.5	" 75 – 80	1.6
" 28 – 29	5.1	" 40 – 45	2.2	" 80 – 85	1.6
" 29 – 30	4.6	" 45 – 50	2.1	" 85 – 90	1.5
" 30 – 31	4.1	" 50 – 55	2.0	......	..

ELASTIC FORCE OF VAPOR OF WATER IN INCHES OF MERCURY, AND WEIGHT OF DRY AIR PER CUBIC FOOT, IN LBS.

$p = 29.92$ at 212°.

Temperature of the air.	Force of vapor in inches of mercury.	Weight of a cubic ft. of dry air, lbs.	Temperature of the air.	Force of vapor in inches of mercury.	Weight of a cubic ft. of dry air, lbs.	Temperature of the air.	Force of vapor in inches of mercury.	Weight of a cubic ft. of dry air, lbs.
T°	p	w	T°	p	w	T°	p	w
0	0.044	0.0864	31	0.174	0.0809	63	0.576	0.0758
1	0.046	0.0861	32	0.181	0.0807	64	0.596	0.0757
2	0.048	0.0860	33	0.188	0.0805	65	0.617	0.0756
3	0.050	0.0858	34	0.196	0.0804	66	0.639	0.0754
4	0.052	0.0855	35	0.204	0.0802	67	0.661	0.0752
5	0.054	0.0853	36	0.212	0.0801	68	0.685	0.0751
6	0.057	0.0852	37	0.220	0.0799	69	0.708	0.0750
7	0.060	0.0850	38	0.229	0.0797	70	0.733	0.0748
8	0.062	0.0848	39	0.238	0.0796	71	0.759	0.0747
9	0.065	0.0846	40	0.247	0.0794	72	0.785	0.0746
10	0.068	0.0845	41	0.257	0.0793	73	0.812	0.0745
11	0.071	0.0843	42	0.267	0.0791	74	0.840	0.0743
12	0.074	0.0842	43	0.277	0.0789	75	0.868	0.0742
13	0.078	0.0840	44	0.288	0.0788	76	0.897	0.0741
14	0.082	0.0838	45	0.299	0.0786	77	0.927	0.0739
15	0.086	0.0837	46	0.311	0.0784	78	0.958	0.0738
16	0.090	0.0835	47	0.323	0.0783	79	0.990	0.0736
17	0.094	0.0833	48	0.335	0.0781	80	1.023	0.0735
18	0.098	0.0831	49	0.348	0.0780	81	1.057	0.0734
19	0.103	0.0830	50	0.361	0.0780	82	1.092	0.0733
20	0.108	0.0828	51	0.374	0.0776	83	1.128	0.0731
21	0.113	0.0826	52	0.388	0.0775	84	1.165	0.0730
22	0.118	0.0824	53	0.403	0.0773	85	1.203	0.0728
23	0.123	0.0822	54	0.418	0.0772	86	1.242	0.0727
24	0.129	0.0821	55	0.433	0.0771	87	1.282	0.0725
25	0.135	0.0819	56	0.449	0.0769	88	1.323	0.0724
26	0.141	0.0817	57	0.465	0.0767	89	1.366	0.0723
27	0.147	0.0816	58	0.482	0.0766	90	1.401	0.0722
28	0.153	0.0814	59	0.500	0.0765	91	1.455	0.0721
29	0.160	0.0813	60	0.518	0.0763	92	1.501	0.0720
30	0.167	0.0812	61	0.537	0.0762	93	1.548	0.0719
..	....	.....	62	0.556	0.0761	..	....	......

EXAMPLE :—

The temperature of the air in a room is 70°; the temperature of the wet bulb is 60°. Required the temperature of the dew point, the weight of vapor in a cubic ft. of air, and the degree of humidity.

Given:	Required (the answer):
$T = 70°.$	$t° = 53°.$
$t_1 = 60°.$	$w_2 = 0.0011377$ lbs.
$t_2 = 70°.$	$R = 0.55.$
$I = 30''.$	$W = 4.38$ grains.
p for $70° = 0.733$ inches.	$I_1 = 29.267$ inches.
w for $70° = 0.0745.$	$w_1 = 0.0726$ lbs.
	$w_4 = 0.0156$ lbs.
	$w_5 = 65.09$ lbs.

$$t = t_2 - (t_2 - t_1)k = 70 - (70 - 60)1.7 = 53°;$$

$$w_2 = 5/8 \times \frac{wp}{I} = 5/8 \times \frac{0.0745 \times 0.735}{30} = 0.0011377;$$

$$w_2, \text{ in grains} = 0.0011377 \times 7000 = 7.96 \text{ grains};$$

$$p_1, \text{ for } 53° = 0.403;$$

$$R = \frac{p_1}{p} = \frac{0.403}{0.733} = 0.55;$$

$$W = w_2 R = 7.96 \times 0.55 = 4.38 \text{ grains};$$

$$I_1 = 30 - 0.733 = 29.267;$$

$$w_1 = \frac{0.0745 \times 29.267}{30} = 0.0726;$$

$$w_4 = \frac{w_2}{w_1} = \frac{0.00113}{0.0726} = 0.0156;$$

$$w_5 - \frac{w_1}{w_2} = \frac{0.0726797}{0.0011377} = 65.09;$$

EVAPORATION.

When moisture must be supplied to the air of ventilated rooms, by the methods just explained, the following formulas give the quantity of water to be evaporated per hour, required for the desired humidity; the superficial area of the water; and the units of heat necessary to produce the evaporation of the water of a given temperature, in a given temperature of the ambient air.

ADDITIONAL REFERENCE:—

A = Area of water surface in sq feet, exposed to the air.
E = Water evaporated, per sq. ft. of surface, in lbs., per hour.
H = Units of heat required to raise 1 lb. of water from 0° to t_3, and then evaporate it.
H_1 = Units of heat lost by radiation from the water, per sq. ft., per hour. See formulas, page 39.
H_2 = Units of heat lost by the air which carries off the vapor from the surface of the water.
K = Pounds of coal required to evaporate the water.
R_1 = The desired per cent. of humidity, generally 70.
s = Specific heat of air = 0.238.
t_3 = Temperature of the water to be evaporated.
U = Units of heat required to evaporate 1 lb. of water.
U_1 = Units of heat required to evaporate W_3 lbs. of water.
u = Units of heat in 1 lb. of coal; generally 6000.
W = Weight of water in lbs. in 1 cubic foot of air before hydration.
W_1 = Weight of water in 1 cubic foot of air, the humidity of which = R_1 in lbs.
W_2 = Weight of water to be evaporated for 1 cubic ft. of air (from R% to R_1% of humidity).
W_3 = Total weight of water to be evaporated per hour.

C = Cubic ft. of air, per hour, to be hydrated.
z = Time in hours necessary to evaporate 1 lb. of water at the temperature t_3.

Water Below the Boiling Point.

$$H = 1081.4 + 0.305\, t_3;$$

$$H_1 = 225\, r\left(1.0043^{t_3 - 32} - 1.0043^{T-32}\right) z;$$

$$H_2 = w_5 s (t_3 - T);$$

$$U = H + H_1 + H_2;$$

$$E = \frac{4.4571}{I}(p - p_1), \text{ for quiet air (no ventilation)};$$

$$E = \frac{4.4571}{I}(p - p_1)\frac{5}{4}, \text{ for air moving};$$

$$z = \frac{I}{E};$$

$$W = w_2 R; \quad W_1 = w_2 R_1; \quad W_2 = W_1 - W; \quad W_3 = W_2 C;$$

$$A = \frac{W_3}{E}; \quad U_1 = W_3 U; \quad K = \frac{U_1}{u}.$$

Heating surface, see u_1 and A_1, pages 77 and 78.

$$A_1 = \frac{U_1}{u_1 (t_4 - t_3)};$$

$$t_4 = \frac{U_1}{A_1 u_1} + t_3.$$

EXAMPLE:—Continued from page 74.

A hall is to be supplied with 3,000,000 cubic feet of air, at a temperature of 70°, per hour. Water at 180°.

$w_2 = 0.0011377$ lbs.
$W = 0.000625735$ lbs.
$R_1 = 0.70$, when saturation $= 1.00$.
$t_3 = 180$.
$I = 30$.

$I_1 = 30 - 15.3 = 14.7$ inches, for 180°.
Temperature of the dew point = 53°.
$p_1 = 0.403$ inches, for 53°.
$u = 6000.$
$w = 0.062$ lbs., for t_3.
$p = 15.3$ inches, for 180°.

$$w_5 = \frac{\frac{w\,I_1}{I}}{5/8\frac{wp}{I}} = \frac{\frac{0.062 \times 14.7}{30}}{5/8\frac{0.062 \times 15.3}{30}} = \frac{0.03038}{0.01976} = 1.53;$$

$$E = \frac{4.4571}{30}(15.3 - 0.403)\frac{5}{4} = 2.76; \quad z = \frac{1}{2.76} = 0.36 \text{ hours};$$

$$H = 1081.4 + (0.305 \times 180) = 1136.3;$$

$$H_1 = 225 \times 1.0853(1.878 - 1.175)0.36 = 62.14;$$

$$H_2 = 1.53 \times 0.238(180 - 70) = 40.1;$$

$$U = 1136.3 + 62.14 + 40.1 = 1238.5;$$

$$W_3 = 0.000170655 \times 3000000 = 512;$$

$$U_1 = 512 \times 1238.5 = 634112;$$

$$W_1 = 0.0011377 \times 0.70 = 0.00079639:$$

$$W_2 = 0.00079639 - 0.000625735 = 0.000170655;$$

$$A = \frac{512}{2.76} = 185.5;$$

$$K = \frac{634112}{6000} = 105.7.$$

Water at the Boiling Point.

$t_3 = 212°$.

ADDITIONAL REFERENCE :—

A_1 = Superficial area of the heated surface in contact with the boiling water, in sq. ft.

t_4 = Temperature of the surface A_1 ($t_4 > t_3$).

u_1 = Units of heat per square foot per hour, emitted by surface A_1.

Values of u_1 : —	u_1 =
For vertical tubes passing through the water............	230
For a double bottomed or steam-cased vessel...........	330
For horizontal tubes, or worm........................	430

$$H = 1081.4 + (0.305 \times 212^\circ) = 1146.06;$$

$$H_1 = 225r(1.0043^{t_3 - 32} - 1.0043^{T-32})z;$$

$$H_2 = 0, \text{ for boiling water};$$

$$U = H + H_1;$$

$$W_3 = \frac{u_1(t_4 - 212)A_1}{966};$$

$$A_1 = \frac{966\ W_3}{u_1(t_4 - 212)};$$

$$t_4 = \frac{966\ W_3}{A_1\ u_1} + 212^\circ;$$

EXAMPLE :—How many pounds of water are evaporated per hour by an open vessel, with a 2 in. diam. pipe passing horizontally through the boiling water, having 20 superficial feet of heating surface, and filled with steam at 260°?

$$W_3 = \frac{u_1(t_4 - 212)A_1}{966} = \frac{430(260 - 212)20}{966} = 427.3 \text{ lbs. per hour.}$$

The evaporation at the boiling point is the most effective and economical.

VENTILATION.

VACUUM SYSTEM.—Steam Jet, Fig. 31.

Steam jets are sometimes applied in the ventilating shaft, at what point is immaterial as to effect; the steam acting as the motive power, by creating a partial vacuum for the air from below to fill, as also impelling the air out of the shaft, similar to blast-pipes of locomotives for increasing the draught through smoke pipe.

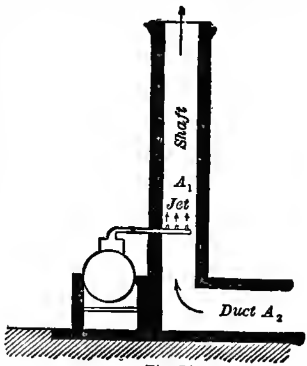


Fig. 31

The percentage of effect of the stem jet is about $\frac{40}{100}$ of the amount of coal consumed.

Diameter of blast pipe, generally ½ inch.

The effectiveness is increased by widening the shaft towards the top.

REFERENCE: —

G = Volume of air, in lbs., passing out of the shaft, per second.

S = Volume of steam, in lbs., passing out of the blast pipe, per second.

A = Area of blast pipe outlet.

A_1 = Area of shaft or chimney.

A_2 = Total area of all air or smoke ducts leading to shaft.

x = Pressure of atmosphere over pressure in chimney or shaft.

h = Pressure of steam in boiler.

h_1 = Pressure of atmosphere = 33.95.

Measured by column of water = 33.95 ft.

p = Pressure of steam in boiler, in lbs., per sq. inch.
a = Coefficient of friction in outlet of blast pipe = 1.663.
$u = \frac{1}{B}$ = Sum of coefficients of friction in ducts leading to shaft; for values of which see f, page 81.

In locomotives, $u = 6$; $B = \frac{1}{6}$.

$$k = \frac{G}{S}.$$

$$\frac{A_1}{A} = m; \quad \frac{A_2}{A} = n; \quad h = \frac{p\ 33.95}{14.7}; \quad m = 1 + \sqrt{1 + Bn^2};$$

$$x = \frac{a(m-1)h}{m^2 - a(m-1) + Bn^2}; \quad \frac{G}{S} = \sqrt{\frac{n^2(m-1)}{u\,m^2 + n}}.$$

ADDITIONAL REFERENCE :—

e = Density of the steam emitted by the blast pipe, (water = 1).
e_1 = Density of the air = 800, for water = 1.
g = Accelerated gravity = 32.166.
v = Velocity of efflux of steam, in ft., per second.
v_1 = Velocity of air in shaft.
C = Cubic ft. of steam emitted per second.
W = Weight of steam emitted per second, in lbs.
W_1 = Weight of air emitted per second, in lbs.
C_1 = Cubic ft. of water to be evaporated by boiler per hour.

$$v = \sqrt{2ghe}; \quad C = vAf;$$

$$W = \frac{62.5 \times C}{e}; \quad W_1 = Wk;$$

$$C_1 = \frac{C3600}{e}.$$

K = Amount of coal consumed per hour.
w = Pounds of water, at 212°, evaporated by 1 lb. of fuel.

Hp = Horse power of boiler.

$$Hp = C_1; \quad K = \frac{C_1 62.5}{w}.$$

Coefficient of Friction, f:—

f = 0.56, orifice in a thin plate.

f = 0.75, short cylindrical pipe.

f = 0.98, short cylindrical pipe, enlarged outward, trumpet shaped.

EXAMPLE:—

Let p = 5 lbs. per square inch, in boiler.

u = Sum of coefficients of friction in ducts and shaft = 6,

$$B = \frac{1}{6}.$$

e = 1250, for steam at five lbs. pressure, when water = 1.

A = 0.00136 square ft.

A_1 = 4.0 square ft.

A_2 = 5.0 square ft.

w = 8 lbs. water evaporated, per lb. of fuel.

$$m = \frac{A_1}{A} = \frac{4.00}{0.00136} = 2941; \quad n = \frac{A_2}{A} = \frac{5.00}{0.00136} = 3676;$$

$$h = \frac{33.95 \times 5}{14.7} = 11.54;$$

$$x = \frac{1.663(2941 - 1)11.54}{2941^2 - 1.663(2941 - 1) + \frac{1}{6}3676} = \frac{56421.60}{6392462.48}$$

$$= 0.009 \text{ feet};$$

$$k = \frac{G}{S} = \sqrt{\frac{3676^2(2941 - 1)}{6 \times 3941^2 + 3676}} = \sqrt{\frac{39728149440}{51900562}} = \sqrt{765.4}$$

= 27.6 times more air than steam, in units of weight;

$$v = \sqrt{2 \times 32.166 \times 11.54 \times 1250} = \sqrt{928003.52} = 963.3 \text{ ft.}$$

per second;

$$C = vAf = 963.3 \times 0.00136 \times 0.75 = 0.982;$$

$$W = \frac{62.5 \times 0.982}{1250} = 0.0491 \text{ lbs};$$

$W_1 = 0.0491 \times 27.6 = 1.355$; for air of $70°$ temp. $= \frac{1.355}{0.075}$ $= 18$ cubic ft. of air per second, being a velocity of

$$v_1 = \frac{18}{4} = 4.5 \text{ ft.};$$

$$C_1 = \frac{0.982 \times 3600}{1250} = 2.82;$$

$$K = \frac{2.82 \times 62.5}{8} = 22 \text{ lbs. of coal per hour.}$$

Computing the velocity of the air in shaft from the pressure, x,

$$v_1 \text{ would} = \frac{\sqrt{2gxe_1}}{\sqrt{u}} = \frac{\sqrt{2 \times 32.166 \times 0.009 \times 800}}{\sqrt{6}} = \frac{\sqrt{463.176}}{2.44}$$

$= \frac{21.52}{2.44} = 8.82$; consequently the per cent. of effect

$= \frac{4.5}{8.8} = 0.51$, or for velocity of 8.8,

$$x = \frac{u\, v_1^2}{2ge_1} \text{ and } h = \frac{m^2 - a(m-1) + Bn^2x}{a(m-1)};\quad p = \frac{h 14.7}{33.95}.$$

HEATING.

FLOW OF STEAM IN PIPES.

The pressure and temperature of steam in a pipe decrease with the length of the pipe and the heat lost per unit of time.

The loss of pressure in the pipe, caused by friction and the loss of heat, does not affect the question of Heating and Ventilation; but the decrease of the temperature of the steam in the pipe, caused by friction, must be known to compute the amount of heat lost or emitted; and to compute the temperature we must know the pressure.

The following formulas give the diminished pressure at the end of long pipes, when the initial pressure in the boiler, and the quantity of water evaporated per hour, are given.

REFERENCE: —

V = Volume of steam in cubic ft., of the pressure P, from 1 cubic foot of water.

v = Velocity of the steam in the pipe, in feet, per second.

C = Number of cubic feet of water evaporated in the boiler, per hour.

P = Pressure of steam in the boiler, in lbs., per square inch.

P_1 = Pressure of steam in the pipe, in lbs., per square inch, at the distance l from the boiler.

l = Length of the pipe in feet, or distance from the boiler where P_1 is required.

d = Diameter of the pipe in inches.

a = Sectional area of the pipe in feet.

f = Coefficient of friction. See page 52.

h = Head of steam for velocity v, in feet.

h_1 = Vertical distance in feet from the boiler to the highest or lowest point that the pipe rises or falls.

g = Accelerated gravity = 32.166.

m = Specific volume of the steam.

$$v = \frac{VC}{3600\,a} = \sqrt{2gh}\,;\ h = \frac{v^2}{2g}\,;\ m = \frac{V}{62.5}.$$

When the pipe rises from the boiler,

$$P_1 = P\left\{1 - \frac{1}{P144m}\left(f\frac{l12}{d}h + h_1\right)\right\}.$$

When the pipe falls from the boiler,

$$P_1 = P\left\{1 - \frac{1}{P144m}\left(f\frac{l12}{d}h - h_1\right)\right\}.$$

For straight pipe without elbows,

$$f = \frac{0.217}{\sqrt{v}},$$ same as for air; see page 23.

EXAMPLE:—

A boiler evaporates 20 cubic ft. of water into steam of 45 lbs. pressure per square inch, per hour; the steam is passed through a pipe, 300 feet long and 2 inches in diameter. What are the velocity of the steam in the pipe and the pressure at the end of the pipe?

$$v = \frac{\frac{562 \times 20}{3600}}{a} = \frac{3.1222}{0.0218} = 143.2\,;\quad f = 0.018\,;$$

$$h = \frac{143.2^2}{2 \times 32.166} = 318.7\,;\quad m = \frac{562}{62.5} = 9.0\,;$$

$$P_1 = 45\left\{1 - \frac{1}{45 \times 144 \times 9}\left(0.018\frac{300 \times 12}{2} - 318.7\right)\right\}$$

$$= 45\left\{1 - \frac{10325.88}{58320}\right\} = 45\,(1 - 0.177)$$

$= 37.035$ lbs. per square inch.

ADDENDA.

LOSS OF HEAT THROUGH WALLS.

All sides of the room exposed (no surrounding rooms), formula, page 36.

$$U = \frac{l_2 cq(T - T_1)}{c(2l_2 + r) + el_2q};$$

Brick Walls.

$T - T_1 = 1°.$

$l_2 = 0.09824 \times 5 = 0.4912$, see page 35.

$c = 4.83$, see page 3 .

$r = 0.7358$, see page 33.

$q = r + l_2 = 0.7358 + 0.4912 = 1.227.$

$$U = \frac{0.4912 \times 4.83 \times 1.227 \times 1}{4.83(2 \times 0.4912 + 0.7358) + e \times 0.4912 \times 1.227}$$

$$= \frac{2.911}{8.299 + e \times 0.6}$$

Stone Walls.

$T - T_1 = 1°.$

$l_2 = 0.4912.$

$c = 22.4$, for coarse marble, being about an average.

$r = 0.7358.$

$q = 1.227.$

$$U = \frac{0.4912 \times 22.4 \times 1.227 \times 1}{22.4(2 \times 0.4192 + 0.7358) + e \times 0.4912 \times 1.277}$$

$$= \frac{13.5}{38.487 + e \times 0.6}$$

TABLE BASED ON THE FOREGOING FORMULA.

Thickness, e, of wall, in inches.	Loss in units of heat, U, per square foot per hour, for a difference of 1° between the external and internal air.	
	Brick.	Stone.
4	0.273	0.330
8	0.223	0.312
12	0.188	0.295
16	0.163	0.280
20	0.144	0.267
24	0.129	0.255
28	0.116	0.244
32	0.106	0.234
36	0.097	0.224
40	0.090	0.216

LOSS OF HEAT THROUGH GLASS (Windows).

Case I.

When the air in a room and the internal surfaces of walls have the same temperature, $T = t = t_2$,

$$U = q(T - t_4);$$

and for a difference between the external and internal temperature of 1°, when $t_4 = \frac{T + T_1}{2} = \frac{1}{2}$,

$$U = 1.086 \times \tfrac{1}{2} = 0.543, \text{ per square foot per hour.}$$

NOTE:—$q = r + l_2$; $r = 0.5948$; $l_2 = 0.4912$.

Case II.

When the air in a room is of a higher temperature than surface of wall opposite to window in question,

$U = 0.45$, per square foot per hour, on an average.

Case III.

When all sides of the room are glass, as in conservatories, and temperature of internal air higher than temperature of internal surface of glass,

$U = 0.35$, per square foot per hour, on an average.

NOTES.

Fresh air inlet openings should be somewhat larger than the exit openings.

The temperature of air in occupied rooms, heated, should be about 70°, to which the heating apparatus must be proportioned, when under full working power, in heating the external air from its lowest known range; see table of "Minimum and Mean Temperature."

In indirect radiation, the top of coil must not be higher than the bottom of heating or hot air flue; while in direct radiation, the bottom of coil must not be lower than the top of fresh air inlet opening.

The smokestack from boilers is generally placed in aspirating chimney, and its heat utilized in rarefying the air in it.

BOILERS.

By *Total Heating surface* of a boiler is understood all that superficial area of the boiler in contact with flames and hot gases from the fire in the furnace—that is, for cylindrical tubular boilers, the lower half of the shell and the whole of all the tubes.

By *Effective Heating surface* is understood a certain mean between that part of a surface receiving the greatest, and that

part receiving the least amount of heat generated in the furnace—it is the whole of a horizontal surface over a fire or hot gas; one half of a vertical surface in contact with a fire or hot gas; three fourths of the lower half of shell exposed to the fire, and half of the area of all tubes or flues heated internally. On an average it is from $\frac{4}{6}$ to $\frac{5}{6}$ of the total heating surface.

For example:—A cylindrical tubular steam boiler, 4 feet in diameter, 15 feet long, and containing 49 tubes, 3 inches in diameter, has a total heating surface of half of the area of shell in addition to the area in the flues, equal to 94 feet in shell (not counting the ends) and 577 feet in flues, total 671 square feet. The effective heating surface of this boiler is: $\frac{3}{4}$ of 94 ft., and $\frac{1}{2}$ of 671 ft., or a total of 406 square feet.

The heat utilized per square foot of total heating surface, is for:—

$$\left.\begin{array}{l}\text{Steam boilers, from 1200 to 3600} \\ \text{Hot water boilers, from 600 to 1800}\end{array}\right\}\begin{array}{l}\text{units of heat per} \\ \text{sq. ft. per hour.}\end{array}$$

On an average, 15 square feet of effective, or 25 square feet of total heating surface, are required per horsepower, the efficiency increasing with the size of the boiler.

A cubic foot of water, evaporated (from 60° to 212°) per hour, is equal to one horsepower, nominal. The following formula is used to compute the *effective* heating surface for steam boilers.

Let A = Total effective heating surface of boiler,
and Hp = Horsepower:

$$A = [Hp + (\sqrt{Hp} = 2.5)] \times 8.$$

Steam boilers for heating purposes are generally proportioned with a greater total heating surface per cubic foot of water evaporated, than those used for power only.

A Hot water boiler requires about twice as much total heating surface as a steam boiler for the same amount of work in units of heat.

It requires about 1118 units of heat to raise the temperature of 1 lb. of water from 60° to 212° and evaporate it; therefore, 1 horsepower will require, $1118 \times 62.5 = 69875$, say 70000, units.

TABLE OF TEMPERATURES.

Minimum and mean temperatures of each month, compiled from observations of the Signal Service, U. S. A., and Blodgett's Climatology of the United States.

NOTE:—In the United States, the comfortable temperature of the air in occupied rooms is generally 70°, when walls have the same temperature.

STATION.	MINIMUM AND MEAN TEMPERATURES OF EACH MONTH.																								No. of mos. fire is required.	Mean temp. of fire mos.	Ave. No. of degrees temp. to be raised.	Max. No. of degrees temp. to be raised.
	Jan.		Feb.		March		April		May		June		July		Aug.		Sept.		Oct.		Nov.		Dec.					
	Min.	Mean	Min.	Mean	Min.	Mean	Min.	Mean	Min.	Mean	Min.	Mean	Min.	Mean	Min.	Mean	Min.	Mean	Min.	Mean	Min.	Mean	Min.	Mean				
Albany, N. Y.	-16	24	-18	25	-4	35	13	47	29	60	40	68	48	72	45	70	33	61	23	49	-10	39	-17	28	7	35	35	87
Baltimore, Md.	-2	31	3	32	9	39	23	52	34	61	49	71	59	75	52	75	40	67	30	55	16	44	1	34	6	39	31	72
Boston, Mass.	-3	27	-5	23	2	36	11	46	32	57	44	66	46	72	50	69	35	62	26	51	-2	40	-11	30	7	37	33	81
Buffalo, N. Y.	-5	23	-13	28	3	30	13	34	29	52	41	64	47	69	46	68	21	65	25	48	2	31	-6	30	8	35	35	83
Burlington, Vt	-16	20	-20	20	1	31	10	42	30	55	43	65	47	70	45	68	32	60	22	48	-10	36	-18	24	7	32	38	90
Chicago, Ills	-20	24	-13	25	5	32	17	46	27	56	40	63	50	71	52	68	37	60	25	48	0	38	-14	29	7	35	35	90
Charleston, S. C.	26	52	28	52	28	60	39	68	47	71	60	81	67	79	63	79	57	76	39	64	28	55	23	51	3	52	13	47
Cincinnati, O.	-7	33	-1	34	13	43	18	54	36	64	49	71	60	76	55	74	41	66	27	53	6	42	-6	34	7	42	28	77
Cleveland, O.	-13	33	-11	33	0	37	15	39	23	60	42	70	50	72	46	70	38	67	26	51	8	37	-5	37	7	38	32	83
Detroit, Mich.	-15	27	-20	27	-2	35	8	46	29	56	38	66	50	70	45	67	35	60	22	48	4	38	-9	27	7	35	35	90
Duluth, Minn.	-38	13	-34	16	-26	24	3	33	26	50	36	58	46	68	45	64	34	59	21	43	-29	24	-30	20	8	28	42	108
Indianapolis, Ind.	-18	36	-8	36	9	42	19	46	31	66	45	77	54	78	48	76	35	70	25	51	-2	37	-15	37	7	41	29	88
Key West, Fla.	50	68	55	74	54	76	61	78	63	80	73	83	73	83	73	84	72	75	65	76	52	73	44	71	0	0	0	26
Leavenworth, Kan.	-20	28	-9	29	2	40	20	49	31	67	37	77	54	83	55	81	37	67	19	57	3	42	-4	32	6	37	33	90
Louisville, Ky.	-10	37	0	39	16	46	21	49	36	68	49	81	58	81	56	79	42	72	28	54	10	41	-5	39	6	42	28	80
Memphis, Tenn.	2	45	13	45	18	53	35	55	44	72	55	81	62	83	63	83	44	73	30	56	25	49	3	44	5	39	31	68
Milwaukee, Wis.	-25	25	-22	29	-3	35	12	41	25	51	40	65	50	70	42	67	32	61	23	51	-14	33	-19	23	8	37	33	95
New Orleans, La.	26	56	32	59	36	66	48	66	56	76	67	81	70	81	70	84	59	79	40	68	39	61	28	57	0	0	0	44
New York, N. Y.	-6	30	-1	30	8	38	20	49	34	59	49	68	57	75	53	73	42	66	31	54	7	43	-2	33	7	40	30	76
Philadelphia, Pa.	-5	32	-1	33	9	42	21	51	36	59	49	69	60	73	55	71	45	64	31	51	8	41	4	33	7	40	30	75
Pittsburgh, Pa.	-12	29	-10	31	2	39	14	50	27	61	43	69	52	73	49	71	36	64	28	51	8	40	-6	31	7	39	31	82
Portland, Me.	-7	20	-7	21	1	30	14	40	34	50	42	59	51	66	48	65	37	57	28	46	-6	35	-12	24	8	33	37	82
Portland, Or.	3	43	24	44	31	45	28	54	36	60	39	60	46	68	43	65	39	61	32	50	27	47	17	37	6	43	27	67
San Francisco, Cal.	36	49	41	51	41	51	40	55	45	58	48	59	49	59	50	59	50	61	49	59	44	57	39	51	4	53	17	34
St Louis, Mo.	-16	33	-3	35	8	44	22	58	32	66	48	74	57	78	55	76	40	69	25	55	11	41	-5	34	5	37	33	86
St. Paul, Minn.	-30	14	-32	14	-15	24	7	37	24	62	39	69	46	75	43	70	30	61	21	41	24	26	-27	19	7	25	45	102
Washington, D. C.	-3	34	-2	37	12	45	22	56	33	66	46	74	58	78	50	76	40	68	26	57	16	45	3	37	5	40	30	73
Wilmington, N. C.	17	50	15	48	22	57	28	63	38	70	53	80	63	79	56	77	50	74	32	61	28	52	15	49	4	50	20	55

Formulas of Prof. Brow[n]idge in San. Engr. 1882
also in Billings' Heating & Ventilation, pp. 197–8,

W = weight in lbs. of air to be discharged per second
T_a = absolute temp. of external air = ($t + 459.4°$) Fahr.
T_s = " " " steam in coil ($= t_s + 459.4°$) "
H = height of shaft in feet (for foul air)
S = No. □ ft. exterior surface of steam coil

A = sectional area in □ ft. of shaft or flue (foul air)
V = velocity of air in shaft or flue, in ft. per sec.
D_c = Density " " " " = 0.0719 lbs/cft.
Usual weight of air = 0.08 lbs per cu ft.
We then have :—

1) $$S = \frac{W T_a}{H(T_s - T_a)} \cdot 1500$$

Taking $V = 5$ ft/sec, & $D_c = 0.0719$, we have

2). $W = A.V.D_c$ ∴ or

3) $$A = \frac{W}{V D_c} = \frac{W}{0.3595}, \text{ or approx. } A = 3.W$$

Example. Room 30' × 40' × 15' = 18000 cft, to have air renewed 4 times per hour; hence
$W = \frac{18000 \cdot 4 \cdot 0.08}{60 \cdot 60} = 1.6$ lbs/sec. ∴ $A = 3.W = 4.5$ □ ft

For low pressure steam; take $t_s = 228^\circ$ or $T_s = 687.4^\circ$
and ext. air in spring — " — $t_a = 60^\circ$, or $T_a = 519.4^\circ$
also assume $H = 50'$; then $(T_s - T_a) = 168.0$

and $S' = \frac{W T_a}{H (T_s - T_a)}$ $1500 = \frac{1500 . 49}{50} = 147.$ □ft

---

1 □ft radiating surface, direct, will heat 75–100 cft.
in halls, factories &c indirect " " 50 – 70 " space
with Steam at 212°

In indirect steam heating, least flue area is 1 to 1 1/4 □ ins for every □ft. heating surface, provided there are no long horizontal reaches of pipe or duct. For hot-water heating, add 30% to these figures

For heating mills, shops, &c., 1 □ft. boiler heating surface is needed for every 475 cft contents; for frame shops, take 400 cft; & when much glass is used, take 275 ft.

The indirect system takes 25% more steam than the direct system.

1 □ft. boiler heating surface will supply from 7 to 10 □ft. radiating surface, in large plants; Each horse-power of boiler will supply from 80 to 120 □ft. radiating surface. Hence in mills, factories, &c:—

1 HP. boiler will supply from 7000 to 10000 cft space.
" " " " = 80 □ft Rad. surf × 100 cft space = 8000 cft
= 120 " " " × 100 " " = 12000 "

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